सत्यमेव जयते

INDIAN AGRICULTURAL
RESEARCH INSTITUTE, NEW DELHI

THE DISEASES OF THE FLAX PLANT

(*Linum usitatissimum* Linn.)

BY

ARTHUR E. MUSKETT, D.Sc., A.R.C.S., M.R.I.A.,
Head of the Plant Disease Division, Ministry of Agriculture for Northern Ireland ;
Professor of Plant Pathology in The Queen's University of Belfast

AND

JOHN COLHOUN, B.Sc., M.Agr., Ph.D., D.I.C.,
Senior Scientific Officer, Plant Disease Division, Ministry of Agriculture for Northern Ireland ;
Lecturer in Plant Pathology in The Queen's University of Belfast

with a Foreword by

Rev. The Right Hon. ROBERT MOORE, B.A., M.P.,
Minister of Agriculture for Northern Ireland

BELFAST
W. & G. BAIRD, LTD.
1947

Publication sponsored by the

NORTHERN IRELAND

FLAX DEVELOPMENT COMMITTEE

Printed in the United Kingdom

FOREWORD

I do not know to what extent the public will be interested in reading the accompanying report of research work done by the Staff of the Ministry of Agriculture on behalf of the Flax Development Committee. But to all into whose hands the volume may come I commend it as a straightforward, unadorned account of very valuable work carried out during the years of war, when flax was such a vital product for the nation.

The successful cultivation of flax presents some of the most baffling problems known to practical farmers. So many factors enter in to complicate experiments that it is well-nigh impossible to disentangle them and evaluate the actual influence of each factor in a truly scientific fashion. As a result, reliable solutions to the problems which confront practical flax growers continue to be extremely elusive. It has been recognised for many years that the seed used has a great influence on the resultant crop. But even when the germination of a particular sample of seed was highly satisfactory, it did not always follow that the crop results were satisfactory. Prior to the war different theories were in circulation as an explanation of such partial failure of crops. Some attributed it to the date of sowing, some to late frosts and so on.

It was left to the research workers of the Ministry of Agriculture to investigate the matter. Professor Muskett and his colleagues undertook the task at the request of the Flax Development Committee which made a substantial contribution from its funds to the cost of the work over a period of years.

It was soon found that the partial failure or unsatisfactory yields from certain crops were in part due to disease carried by the flax seed. The disease spores were not visible to the naked eye and did not prevent the seed from germinating, but began to develop after a longer or shorter period from the start of the young flax plant's growth, the period depending upon climatic and other conditions.

The task which the research workers of the Faculty of Agriculture at Queen's University undertook was not only to identify the different seed-borne diseases which attack the flax crop in Northern Ireland, but

to find some form of treatment which could be applied to the seed before sowing, which would be effective in controlling the incidence of the different diseases, and would not injure the germination of the seed or reduce the seed to such a physical condition that uniform distribution at sowing time would be made difficult or impossible.

The pages which follow with the photographs and illustrations attached tell the story of how experimental methods were evolved, and how the task was accomplished. It is not suggested that all the problems of flax culture have been solved, but at least as a result of the work recorded in this book a considerable number of the risks have been greatly minimised, if not entirely removed. So much so that, although the acreage under the crop went up to as much as 124,000 towards the end of the war, yields per acre did not fall to anything like the same extent as during the 1914-18 period.

Owing to labour and other production costs flax growing in Northern Ireland has fallen into disfavour again. Whether under different conditions it will come back into more extensive cultivation than at present, I do not care to predict, but the value of the work covered by the pages, to which this is a foreword, will remain.

Minister of Agriculture.

April, 1947.

CONTENTS

INTRODUCTION

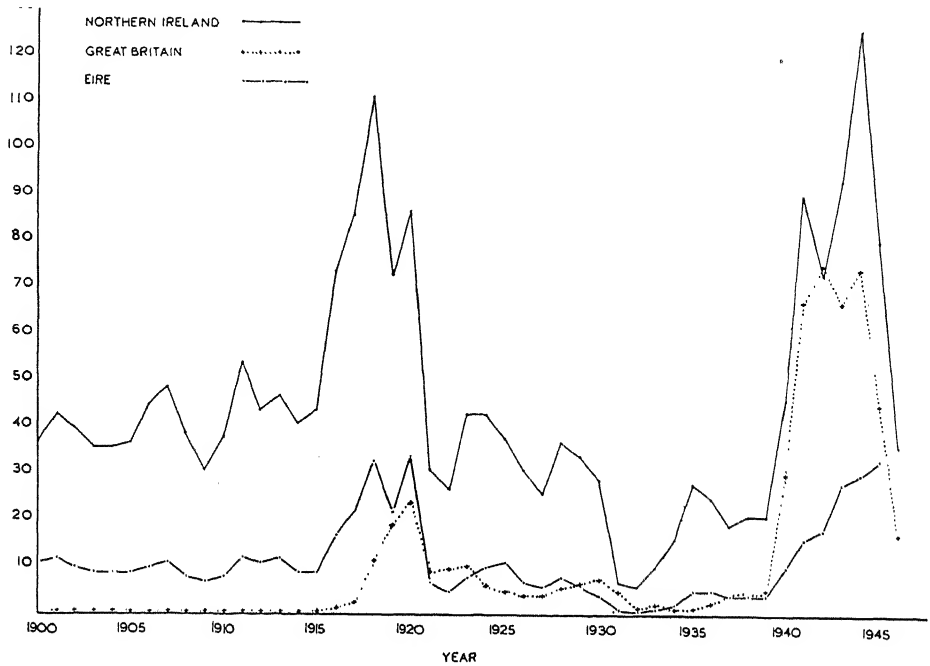
Although the growing of fibre flax (*Linum usitatissimum* Linn.) for the manufacture of linen is one of the oldest established rural industries in the British Isles, it is in Ireland and particularly in Northern Ireland, that it has been centred for a long time past. This is undoubtedly due to Ulster being the home of the British linen industry and to the fact that a proportion of Northern Ireland farmers regard flax growing as indigenous to their farming practice. Nevertheless, in normal times only a small proportion of the fibre required by the linen industry is produced at home, the bulk of it being imported from Belgium, Holland and Russia. That the growing of flax may be a more speculative venture than is the case with most tillage crops and that the uncertain nature of the enterprise is aptly expressed in the common adage that flax may be " all copper or all gold," is borne out by the striking variations which can occur from year to year in the yield of scutched fibre together with the marked fluctuations in the price. In spite of this, flax cultivation has persisted in Northern Ireland and there is no doubt that an able farmer with suitable land and adequate knowledge and experience will find flax to be a useful cash crop in his farm economy for so long as it is cultivated for its fibre.

The acreage of flax in Ireland shows considerable fluctuation from year to year but, as is clearly shown by the data provided in the following graph showing the acreages under flax in the British Isles from 1900-1946, very marked peak periods of production have always occurred in times of national emergency when outside sources of supply have been cut off and supplies of cotton and other natural fibres restricted. This is only to be expected but, even so, the erratic fluctuations which occur are such as to suggest that anything which can be done through the medium of scientific research and a better planned crop economy to place the growing of flax on a sounder and more stable basis should be generally beneficial.

That the incidence of disease in the flax crop may be a factor responsible for significant depressions in the fibre yield was recognised by the Irish Department of Agriculture and Technical Instruction in 1917 when the investigation of flax diseases was specifically undertaken by the Plant Disease Division. This investigation was continued until 1921 when it lapsed and from then until 1938 when it was renewed by the Plant Disease Division of the Ministry of Agriculture for Northern Ireland no consistent work was carried out in the British Isles. The recommencement of the work in 1938 was made possible through a grant-in-aid made to the Ministry of Agriculture for Northern Ireland by the Northern Ireland Flax Development Committee which had included the study of disease and its control in its programme of investigational work planned with the object of bringing greater encouragement and stability to the growing of flax in Northern Ireland.

In this monograph some account is given of the diseases of the flax plant and their control in the hope that the provision and dissemination of this knowledge will lead to the production of healthier crops with a

heavier and less variable fibre yield. It is felt that little comment upon the mode of presentation of the work is necessary ; the aim has been to achieve such a measure of straightforwardness and simplicity as to make the subject intelligible to the lay reader as well as to the agricultural scientist and the farmer. The bibliography given for each disease is not complete but it includes all the known works of importance of which the writers are aware ; those of special import and without reference to which a full and detailed knowledge of any disease and its control cannot be gained, are printed in heavier type.



Graph showing the annual acreages under flax in the British Isles from 1900-1946. The acreages for Great Britain are inclined to be exaggerated as for some years they include the acreage under flax for linseed as well as that under fibre flax. In the case of Northern Ireland and of Eire the acreages given are for fibre flax only in all cases.

Special attention is drawn to the four appendices which complete the work. These deal respectively with the Ulster method devised for the examination of flax seed for the presence of fungal parasites, seed disinfection, the production and certification of seed, and the growing of a healthy flax crop. The significance of the first three lies partly in the fact that they tell something of the story of the United Kingdom war effort to secure an adequate supply of fibre in a time of national emergency when the country was denied supplies from other sources. The fact that it is now possible, by routine methods of testing, to examine the total flax seed output from any area for the presence of seed-borne parasites of major importance, may be of far reaching consequence. In the case of

other crops, as well as flax, the danger of serious crop losses occurring through disease caused by seed-borne parasites is very real and the importance of being able to examine seed bulks rapidly and accurately for the presence of such parasites cannot be over emphasised. It may well be that, in the course of time, the routine examination of all seed for its health and for the presence of disease causing organisms will be as generally practised as is its examination today for the degree of its purity and its germination capacity. The whole flax seed output of the United Kingdom has been systematically examined in this way for the past three years and the cost of the work has been such that the expense would be completely covered by the saving of a few acres of crop through preventing the sowing of seed heavily contaminated with parasites or by the recommendation of appropriate treatment to reduce any possible damage to a minimum. Appendix II, which deals with seed disinfection, gives some account of the effort made during the war years to eliminate the danger of seed-borne parasites by disinfecting the seed in order to destroy them. Flax seed produced in the more north-westerly and wetter districts of the United Kingdom frequently becomes heavily contaminated with fungal parasites and as the use of such seed was essential during the emergency, the discovery of an effective method of seed disinfection was of great importance. This effort was attended by a large measure of success for a suitable means of seed disinfection was discovered whereby it became possible to prevent the damage caused by seedling blight and grey mould, to secure a high degree of control of stem-break and browning and a partial control of foot rot. The disinfection process was first applied in Northern Ireland, where the original research had been undertaken, and later adopted throughout the United Kingdom so that all seed produced for sowing purposes became disinfected as a routine measure. In order that the farmer should be supplied with tested seed of the best available quality, a scheme for the certification of flax seed produced in Northern Ireland was introduced in 1940 and this is described in Appendix III. But the good health and high quality of a crop is not solely dependent upon the use of pure seed and prophylactics, important as these may be ; the application of the principles of good crop husbandry is of the greatest importance. In Appendix IV will be found some observations upon the method of husbandry required by the crop in order that its good health may be better ensured.

Much of the work described in these appendices was undertaken at a time of great national stress when, owing to the gravity of the situation, it was comparatively easy to make arrangements for the examination of all flax seed produced in the country and for the disinfection of the seed on a nation-wide scale. This is probably the first time that such an undertaking has been achieved and it is of interest to note that it was achieved without compulsion ; it was a voluntary effort on the part of all concerned and cheerfully undertaken with the united goodwill and co-operation of Government, University and Industry. Northern Ireland will not need to produce bulk supplies of flax seed in the time of peace.

and it may be that it will be the lot of this work to be shelved until a future state of emergency arises. It is hoped, however, that the lessons of war will not be forgotten in the less exacting times of peace because what was done for flax seed in Northern Ireland in the time of war could and should have a far-reaching effect upon the handling of seed from many crops in all parts of the world in the more normal time of peace.

As the bulk of the matter discussed in this book holds equally well for linseed as for fibre flax, it is hoped that it will be of use to all who cultivate *Linum usitatissimum* either for fibre or for oil.

The writers wish to take this opportunity of thanking all those who have contributed in any way whatsoever towards bringing this work to a successful conclusion. The carrying out of the research upon the results of which the compilation of a considerable portion of the work is based and which results have been published from time to time in various scientific journals was made possible, as has already been indicated, by a grant-in-aid from the Flax Development Committee. Thanks are also due to the Committee for the unfailing interest shown by its Members and for sponsoring the publication of the present work. Due acknowledgement is made to Mr. E. L. Calvert, M.Agr., who has assisted generally with the experimental work, and to Mr. C. W. R. McCreary, M.Sc., who has co-operated in connection with the sections dealing with flax wilt and Braid Valley disease. To Mr. J. P. Malone, B.Sc., who assisted so ably with the preparation of the numerous photographs illustrating the work, special acknowledgement is also made.

SEEDLING BLIGHT

(*Colletotrichum linicola* Pethybr. & Laff.)

General

The disease of flax known as seedling blight in the British Isles is caused by the parasitic fungus *Colletotrichum linicola* Pethybr. & Laff., and has been recorded in nearly every country where the crop is grown either for fibre or oil. It is known to occur in Belgium, the British Isles, Canada, Formosa, France, Germany, Holland, Japan, Latvia, Lithuania, New Zealand, Poland, U.S.A. and the U.S.S.R. (including Siberia), in most of which countries its incidence has resulted in appreciable crop losses.

The fungus is normally seed-borne and is carried by the seed as mycelium or spawn located in the outer layers of the seed coat. Spores (conidia) are also found adhering to the seed but the mycelium is largely responsible for carrying over the parasite. When a contaminated seed is sown and commences to germinate, warm moist soil conditions also stimulate the growth of the fungus which develops in the outer layers of the seed coat and produces large numbers of spores, any one of which is capable of germinating and infecting the young seedling providing the conditions are suitable. The seed coat is frequently carried above ground attached to the tips of the seed leaves and sometimes it may be found attached to the young stem. The chances of infection are thereby increased and it is under these circumstances that the disease is most readily contracted. One or both seed leaves may be attacked and the symptoms are most easily noticeable in the crop when the young plants are from two to three inches in height and have developed several pairs of secondary leaves (Fig. 1). The leaf lesion first becomes evident as a small circular area with a watersoaked appearance, the colour changing from light dull green to reddish brown as the tissues are killed and become dried out. It spreads comparatively rapidly and within a few days the whole leaf is involved and ultimately becomes brown and shrivelled. Under ideal conditions for the spread of the disease the growing point of the young seedling may be attacked and the plant killed outright. Spores are normally produced in abundance on the infected seed leaves and are washed down the stem of the seedling by rain or heavy dew. This is one way in which the stem may become attacked, the point of infection most frequently occurring at the collar of the plant at or just below soil level. The symptoms here consist of a cankering and shrivelling of the affected region of the stem which is often orange red in colour (Fig. 1). The discolouration is not directly due to attack by this particular parasite ; it is a function of the plant and a somewhat similar colour reaction may be produced as the result of mechanical or insect injury. If the lesion girdles the stem the plant is killed and falls over at the point of attack. Seedlings which contract slight stem canker and are not killed may grow on to reach maturity, the plants thus produced being frequently thin, stunted and sub-normal. Therefore, apart from causing the death of the

young plant, the disease may affect a proportion of the grown crop and by the production of sub-normal plants adversely affect the fibre yield. The thinning out of the plants resultant upon the deaths of seedlings also results in unevenness of crop which encourages the production of stems of unequal thickness thereby affecting the quantity and quality of the fibre produced. The extent to which infection occurs will depend largely upon weather conditions at brairding time, the onset of the disease in epidemic form being most favoured by continuous wet warm weather. Thick sowing favours the rapid spread of the disease in the crop and the first outbreaks of infection are most readily observed where the seedlings tend to occur in clumps due to the slight but inevitable unevenness of sowing.

If an affected plant is examined with a strong hand lens the fungus can easily be recognised as, at the time of spore formation, it produces a number of pointed dark coloured hairs (setae) which project from the tiny coral pink bee-hive shaped spore masses (acervuli) and form a typical and reliable character for its recognition (Figs. 2-4). The sporing stage is nearly always present on seedlings attacked in the field and the examination of unhealthy plants for the presence of acervuli with their accompanying setae, may be regarded as a fairly reliable guide as to whether or not the disease is seedling blight. Photographs of a typical colony of the fungus growing on a nutrient medium and of a group of the unicellular sausage shaped spores produced by the fungus are shown in Figs. 5 and 6.

The seed contracts infection through the medium of the boll which becomes attacked by the parasite. The wall is penetrated and the fungus reaches the seed by way of the central axis and the short stalk (funicle) by which the seed is attached. The boll may be reached by the fungus attacking successively higher leaves as the crop develops and being thus brought into close proximity with the bolls by the time the crop is mature. The sepals of the flowers which fade and die soon after the time of blossoming form a suitable medium for the growth and development of the fungus. During the growing season the fungus may continue to sporulate on plants which have been killed or on stem cankers at the bases of affected plants. Such spores may be dispersed by wind, rain and insects and so directly reach the dying sepals at the bases of the bolls. In the case of crops which become lodged before pulling, the chances of seed infection are greatly enhanced as the boughs are brought near soil level where infection risks are greater and favoured by the more moist conditions which prevail.

At the time of pulling as well as in crops of green flax which have been stacked before retting or scutching, it is not uncommon to find straws which are infected with the disease throughout their entire length. If green flax is stored under damp warm conditions suitable for the growth and development of the fungus, the disease may spread in storage and so increase the quantity of damaged staws and infected seed while, under suitable conditions, further contamination of the seed may occur during the operation of de-seeding.

Although seedling blight may normally be regarded as a seed-borne disease, the possibility of its being soil-borne must not be overlooked. That it can be contracted by seedlings grown from non-contaminated seeds sown in soil mixed with chopped up flax straws infected with the parasite, has been proved experimentally and, knowing this, it is essential that the soil be kept as free as possible from an accumulation of flax straw detritus.

The incidence of seedling blight is related to the degree of contamination shown by the seeds sown and this relationship is closer at low or moderate than at high levels of seed contamination. Consequently, the damage which may result in a crop from an outbreak of the disease will be governed by the extent of seed contamination. Very frequently the effect of the attack is not reflected in the yield of straw although the yield and quality of the fibre are significantly reduced. That considerable reductions in the yield of long fibre can accompany epidemic outbreaks of the disease has been proved since it has been shown that in a year when seed contaminated to the extent of 31 per cent. was used the fibre yield was 3.1 cwt. per acre whereas, when seed from the same sample was disinfected before sowing, with the consequent elimination of the seedling blight parasite, the fibre yield was increased to 5.9 cwt. per acre.

Prevention and Control

Seedling blight, as a seed-borne disease, may be completely prevented by disinfecting the seed with dressings in powder form such as " Nomersan " and " Arasan " which contain tetramethylthiuram disulphide as their active constituent ; for this purpose they are applied at the rate of 12 oz. per cwt. of seed. Organo-mercurial seed dressings in powder form as used for seeds of cereals are not so satisfactory for this disease of flax although treatment by the short wet method using a solution of an organo-mercurial is satisfactory (see Appendix II). Although seed disinfection will prevent the disease from occurring in the crop it does not ensure the seed from the crop being free from contamination and experience has shown that disinfection must be carried out each year as routine practice.

The incidence and spread of seedling blight is encouraged by warm wet weather and earlier sowing may be effective in preventing the occurrence and retarding the spread of the disease if by advancing the sowing date, cool conditions for the development of the seedlings are ensured. Even sowing of the seed and thereby avoiding the clumping of seedlings is effective in reducing crop damage.

The danger of flax crops contracting seedling blight through contaminated soil is best avoided by the adoption of an adequate crop rotation, whereby the growing of flax too frequently in the same land is avoided. At the same time care should be taken to prevent quantities of flax straw detritus from reaching land in which it is proposed to grow flax immediately.

Marked varietal differences in resistance to this disease have been observed but little such resistance occurs in flax varieties cultivated for fibre ; it is more marked in those grown for oil. At present no commercial varieties of fibre flax can be recommended for growing as resistant to seedling blight but there is no reason to suggest that such varieties may not be available in the future.

The control of the disease by storage of the seed until the parasite has died out and is no longer viable would not seem to be a practicable measure as it has been shown in work not yet published that the seedling blight parasite can remain viable in the seed for more than five years. The storage of seed, even under ideal conditions, for such a long period cannot be recommended in general practice.

REFERENCES

Bolley, H. L. & Manns, T. F. (1932). Fungi of flaxseed and of flax-sick soil. Bull. 259. Agric. Exp. Sta. N. Dak. Agric. Coll.

Colhoun, J. (1946). The relation between the contamination of flax seed with *Polyspora Lini* Laff. and *Colletotrichum linicola* Pethybr. & Laff. and the incidence of disease in the crop. Ann. appl. Biol. 33, 260-263.

Hiura, M. (1924). On the flax anthracnose and its causal fungus, *Colletotrichum Lini* (Westerdijk) Tochinai. Jap. J. Bot. 2, 113-131.

Muskett, A. E. & Colhoun, J. (1940). Prevention of seedling blight in the flax crop. Nature, Lond., 146, 32.

Muskett, A. E. & Colhoun, J. (1941). Prevention of stem-break, browning and seedling blight in the flax crop. Nature, Lond., 147, 176-177.

Muskett, A. E. & Colhoun, J. (1943). The prevention of seed-borne diseases of flax by seed disinfection. Ann. appl. Biol. 30, 7-18.

Muskett, A. E. & Colhoun, J. (1944). The prevention of seed-borne diseases of flax by seed disinfection. II.—Comparison of the dusting, short wet and fixation methods of treatment. Ann. appl. Biol. 31, 295-300.

Pethybridge, G. H. & Lafferty, H. A. (1918). A disease of flax seedlings caused by a species of *Colletotrichum* and transmitted by infected seed. Sci. Proc. R. Dubl. Soc. N.S. 15, 359-384.

Ray, C. (1945). Anthracnose resistance in flax. Phytopathology, 35, 688-694.

Tochinai, Y. (1925). Comparative studies on the physiology of *Fusarium Lini* and *Colletotrichum Lini*. J. Coll. Agric. Sapparo 14, 171-236.

FIG. 1—Two flax seedlings attacked by seedling blight. Both show typical stem lesions. In the case of the seedling on the left, one cotyledon has been attacked and killed, while in that on the right both have become involved. Seedlings attacked in this manner will not survive.

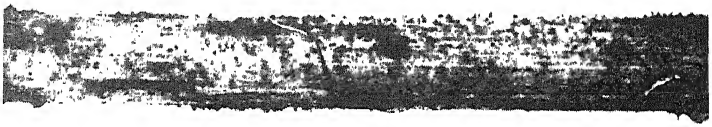


FIG. 2—Flax straw showing the abundant production of acervuli (x 7).

FIG. 3—Flax straw with typical acervuli and setae (side view) (x 45). Mean length of seta—150μ

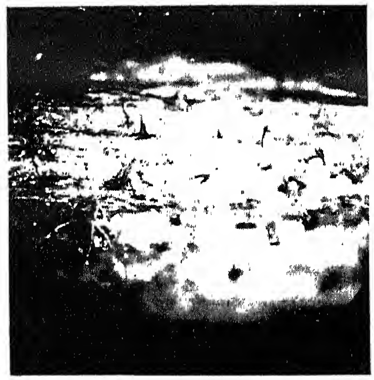


FIG. 4—Flax straw with typical acervuli and setae (surface view) (x 25).

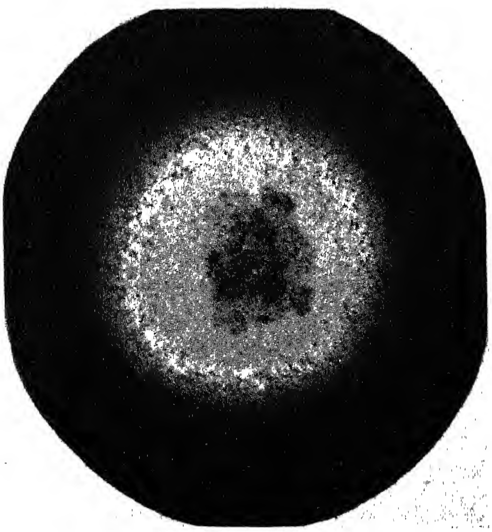


FIG. 5—Typical colony of *Colletotrichum linicola* growing on 2 per cent. malt agar medium.

FIG. 6—Typical group of spores produced by *Colletotrichum linicola* (x 300). The actual size of the spore ranges from 16-18μ x 3-5μ.

STEM-BREAK AND BROWNING

(*Polyspora Lini* Laff.)

General

Stem-break and browning is a seed-borne disease of flax caused by the fungus *Polyspora Lini* Laff. It occurs in Australia, the British Isles, Canada, Denmark, Holland, Kenya, Latvia, New Zealand, Poland, U.S.A. and U.S.S.R. (including Siberia).

The way in which the parasite is carried by the seed and the disease contracted by the seedlings is the same as for seedling blight. In the seedling phase of the disease the seed leaves are attacked but the stem usually remains unaffected. The lesions may be distinguished from those of seedling blight by their darker colour, their more regular circular shape and their slower increase in size (Figs. 7-9). The parasite is slower growing and a period of some weeks may elapse from the time the attack is first observed until the death of the leaf. Observations for the presence of this phase of the disease are best made some four weeks after sowing and at about the same time as for seedling blight. As with seedling blight, the disease is more readily observed where the seed has been sown thickly and the plants tend to occur in clumps. The seedling attack may not kill the plant and frequently causes little damage to the crop ; its significance lies in the fact that it provides the inoculum for the stem-break and browning phases which occur later in the season.

The limp and dead seed leaves which have been killed by the disease usually remain attached and become stuck to the stem and it is by their spreading infection to the straw that the stem-break phase of the disease is normally contracted. This phase becomes apparent some seven to eight weeks after sowing by which time, in a normal season, the crop will be in an advanced stage of growth. The attack on the stem occurs at seed leaf level about one inch (2.5 cm.) or less above the soil surface and its effect is to produce a canker and weaken the stem at this point so that it tends to break. In severe cases a break does occur and the stump of the stem base is left projecting above the soil surface but, more usually, the stem bends over sharply at the point of attack and the plant, in regaining its upright posture, becomes distinctly bow-shaped in appearance. Many of the affected plants are sub-normal in character and have a reduced fibre value while it is not uncommon for an attack by another fungus (*Fusarium* sp.—see p. 62) to follow on and complete the rot of the stem in the neighbourhood of the canker ; in such cases the plant dies prematurely. If the attack is widespread in the crop the effect of wind and rain on the weakened plants will be such as to cause the whole crop to become lodged and its fibre value thereby largely destroyed. In slow growing or backward crops the stem-break phase of the disease may set in before the crop has reached an advanced stage of growth. Illustrations of stem-break affecting the crop at different stages of growth are shown in Figs. 10-12.

The browning phase of the disease does not occur in Northern Ireland until about the end of July shortly before the crop is pulled. It becomes noticeable by the appearance of brown patches scattered through the crop, the browning being largely confined to the region of the boughs of the plants. A close inspection of an infected plant shows that the browning effect is due to the production of numerous definite lesions, dark in colour, on the branches of the boughs and on the bolls. To diagnose the presence of browning it is necessary to make this inspection because under certain conditions of soil and season the boughs of the plants may become bronzed in appearance as the crop approaches maturity. (See " Bronzing.") Illustrations of browning lesions as they occur on mature flax straws are shown in Fig. 14. If damp and warm weather conditions prevail, the browning phase may spread throughout the crop within the course of a few days. The presence of the disease in the neighbourhood of the boughs may not be serious in so far as it effects the production of long fibre but when the lesions also occur, as they frequently do, on the main stem then an impaired fibre yield results. Apart from this the occurrence of the browning phase is of great importance in that it brings about the infection of the seed. The parasite gains a foothold on the dying sepals (Fig. 13) after the plant has flowered and then proceeds to attack the ripening bolls which it penetrates, and reaches the developing seed by way of the central axis and seed stalk (funicle). If the attack takes place relatively early, the seed becomes affected when it is very immature ; its development is impeded and it is frequently killed. When the seed is not killed, the prevention of its healthy development leads to the production of a proportion of light seeds with the result that the yield may be substantially reduced. It is, therefore, of interest to note that in the case of this disease, the seed may not only carry the parasite as a contaminant but it may be attacked by the parasite and suffer impeded development or, in extreme cases, be killed outright.

The fungus produces spores freely on the surface of the diseased tissues. Large numbers of tiny creamy white pustules are formed at this stage, each of which is composed of a mass of unicellular and somewhat irregularly shaped spores. These pustules may be readily seen with the aid of a hand lens but as their characteristics are not so well defined as in the case of *Colletotrichum linicola*, it is usually more satisfactory to confirm the diagnosis by microscopic examination. Fig. 15 shows the pustules present in abundance on a browning lesion of a diseased flax straw while Figs. 16-18 show a typical colony of the fungus growing on a nutrient medium and a group of the irregularly shaped unicellular spores.

When an epidemic of stem-break and browning occurs the yield and quality of the fibre produced is greatly impaired. For example, in two years when in experimental crops the seed sown was naturally contaminated with the parasite to the extent of 23.7 per cent. and 50.4 per cent. respectively, the increases in yield of fibre brought about by using a seed disinfectant which substantially reduced the intensity of the attack, varied from 40 per cent. in the first year to as much as 370 per cent. in the second.

Prevention and Control

Although seed disinfection with " Nomersan " or " Arasan " provides a good measure of control, these materials are not so effective as in the case of seedling blight. The short wet method of disinfection using a solution of an organo-mercurial has been found to be the most satisfactory large scale method up to date. The fixation method whereby an organo-mercury dust is fixed to the seed by the use of water (see Appendix II) has also been found to be quite satisfactory. For use with small contaminated stocks of valuable seed a method of hot water treatment has been elaborated in New Zealand. In this method the difficulty caused by the swelling of the outer mucilaginous layer of the seed coat on its immersion in water is overcome by the use of hydrated lime which is thoroughly mixed with the seed at the rate of 8 oz. per cwt. (4.5 gm. per kg.). The seed is then steeped for 10 minutes in water to which 1 per cent. of hydrated lime has been added and the temperature of which has been raised to 126° F. (52° C.). It is then transferred to cold water, to which 1 per cent. of hydrated lime has also been added, for a few minutes before being dried.

The extent to which the different phases of the disease will occur depends in some measure upon the season although it has been shown that the general incidence of the disease in a normal season is directly proportional to the degree of contamination of the seed sample used, and this is more particularly obvious at low or moderate than at high levels of seed contamination. In view of this, bulk seed stocks showing contamination to the extent of more than 10 per cent. should not be used for sowing but should be discarded and used for feeding or crushing unless they can be treated by a method of disinfection known to provide the highest measure of disease control. Seed contaminated to the extent of 10 per cent. or less should be disinfected with " Nomersan " or " Arasan " before sowing although one of the more effective methods should be used if practicable. Although seed disinfection will normally reduce the incidence of the seedling and stem-break phases to a minimum, it is, as would be expected, the browning phase which presents the most difficult problem. It has repeatedly been observed that the onset of browning is delayed up to 14 days by seed disinfection even in cases where the seed used is contaminated to the extent of 50 per cent. This is important as it allows more time for the pulling of the crop before infection becomes general. The seedling phase is encouraged by warm wet weather and early sowing under cooler conditions will assist in keeping an outbreak under control. Earlier sowing will also allow of earlier pulling so that the adoption of the practice of seed disinfection and earlier sowing should help materially towards the crop being grown and pulled before an attack of browning occurs or becomes epidemic.

The incidence of the stem-break and browning phases is not unconnected with the soil conditions under which the crop is grown and, generally speaking, both these phases tend to be much more severe when the crop is grown in rich land on the heavy side which is likely to produce

lush soft growth. Although the seedling phase commonly occurs irrespective of soil conditions, it has been observed that crops grown in light sandy soil from seed contaminated to the extent of 15 per cent. remain relatively free from both stem-break and browning whereas those grown in heavy rich loam from the same seed sample contract severe infection.

No variety of flax has yet been produced which is immune to attack by the parasite although one large seeded oil variety, Rio, has been found to be almost immune. Among the fibre producing varieties a considerable degree of resistance is shown by Herkules, Concurrent and Linkopis while the Stormont and Liral varieties have proved to be very susceptible.

When seed contaminated with the parasite is stored under normal conditions the fungus may remain viable for more than four years after the time of harvest. Because of this, as was also the case with *Colletotrichum linicola*, storage of seed until the parasite has died out cannot be recommended as a means of disease control.

REFERENCES

Baylis, G. T. S. (1941). Stem-break and browning (*Polyspora Lini*) of flax in New Zealand. N.Z.J. Sci. 23, 1A-8A.

Colhoun, J. (1946). Observations on the effects of browning (*Polyspora Lini* Laff.) of flax on seed production. Ann. appl. Biol. 33, 255-259.

Colhoun, J. (1946). The relation between the contamination of flax seed with *Polyspora Lini* Laff. and *Colletotrichum linicola* Pethybr. & Laff. and the incidence of disease in the crop. Ann. appl. Biol. 33, 260-263.

Henry, A. W. (1934). Observations on the variability of *Polyspora Lini* Laff. Canad J. Res. 10, 409-413.

Lafferty, H. A. (1921). The browning and stem-break disease of cultivated flax (*Linum usitatissimum*) caused by *Polyspora Lini* n. gen. et sp. Sci. Proc. R. Dubl. Soc. 16, 248-274.

Muskett, A. E. & Colhoun, J. (1941). Prevention of stem-break, browning and seedling blight in the flax crop. Nature, Lond., 147, 176-7.

Muskett, A. E. & Colhoun, J. (1943). The prevention of seed-borne diseases of flax by seed disinfection. Ann. appl. Biol. 30, 7-18.

Muskett, A. E. & Colhoun, J. (1944). The prevention of seed-borne diseases of flax by seed disinfection. II.—Comparison of the dusting, short wet and fixation methods of treatment. Ann. appl. Biol. 31, 295-300.

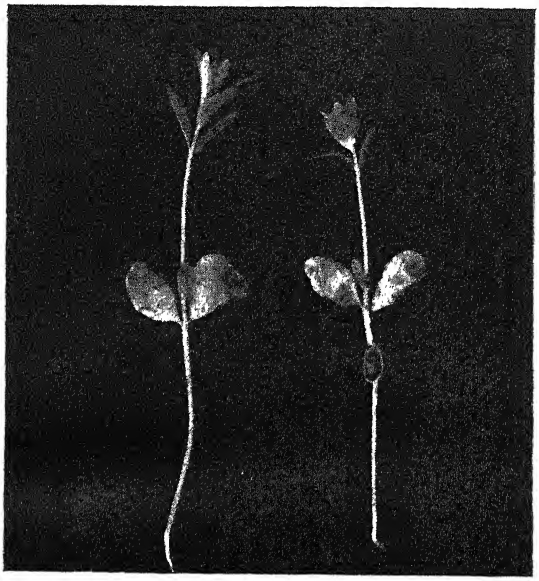


FIG. 7—Two plants affected with the seedling phase of stem-break and browning. The circular lesions produced on the seed leaves are clearly seen in each case. In the seedling to the left the seed coat remains attached to one of the seed leaves, while in that to the right it is attached to the young stem.

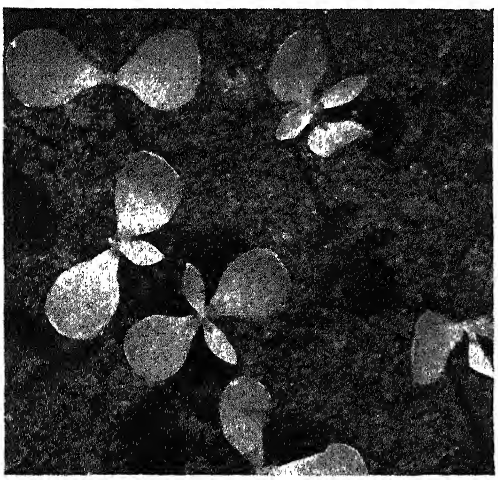


FIG. 8—Flax seedlings sprayed with sterile water. They have remained healthy.

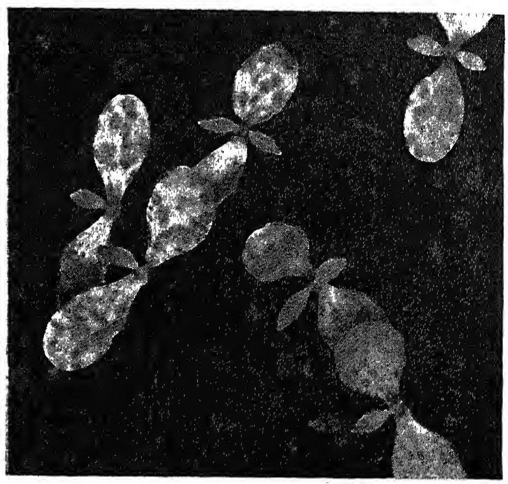


FIG. 9—Flax seedlings sprayed with a water suspension of the spores of *Polyspora Lini*. Infection has taken place and the symptoms of the seedling phase of the disease are apparent.

FIG. 10

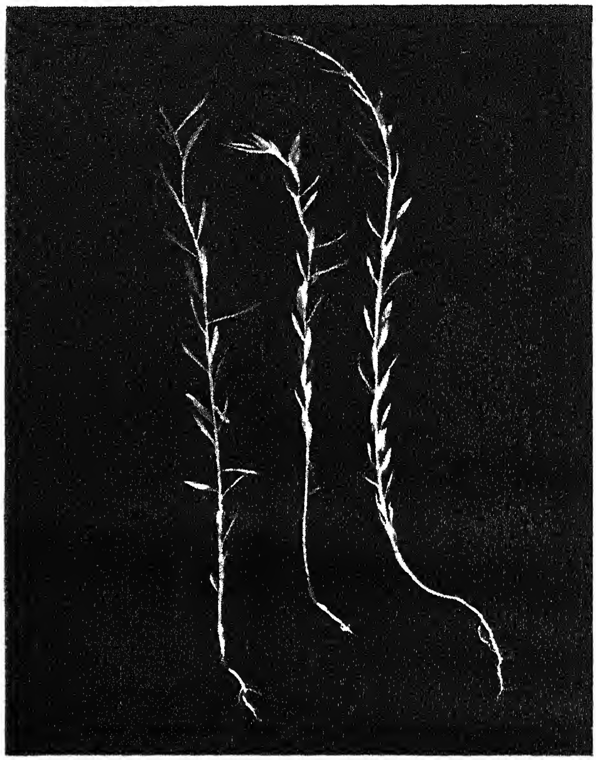


FIG. 11

FIG. 12

FIGS. 10-12—Flax plants affected with stem-break. Those in Fig. 10 were taken from a very backward crop checked by cold weather and which had contracted the disease at a comparatively early stage of development. In Fig. 12 the crop was almost fully grown while Fig. 11 represents an intermediate stage. Note how the stem-break lesion always occurs at the level of the seed leaves which normally provide the medium for stem infection.

FIG. 13—The first stage of the browning phase of the disease. This illustration shows the parasite established on the dying sepals which surround the ripening seed bolls of the plants.

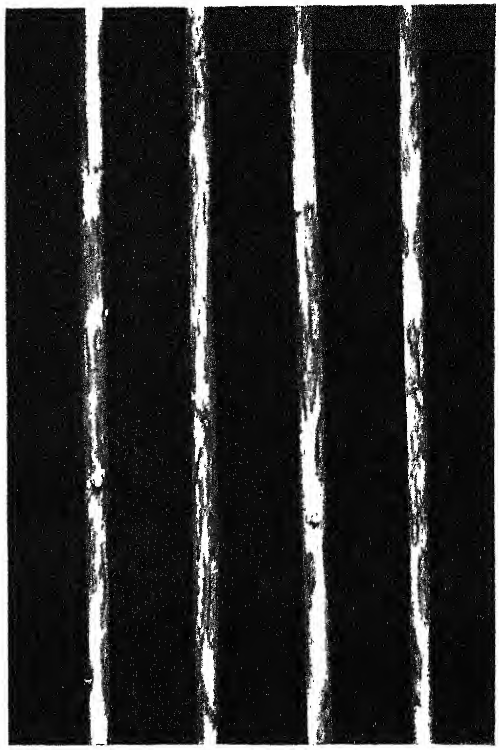


FIG. 14—Mature flax straws affected with browning lesions.

FIG. 15—Enlarged photograph of a browning lesion showing the production of an abundance of the minute creamy white spore pustules (x 8).

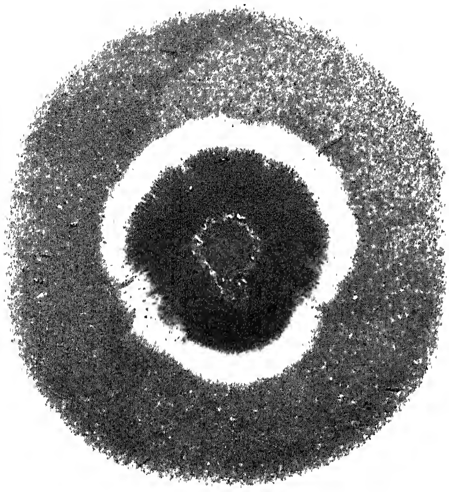


FIG. 16—Typical colony of *Polyspora Lini* growing on 2 per cent. malt extract agar.

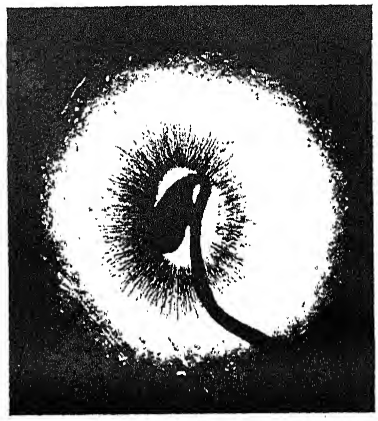


FIG. 17—A typical colony of the fungus growing from a contaminated flax seed (enlarged).

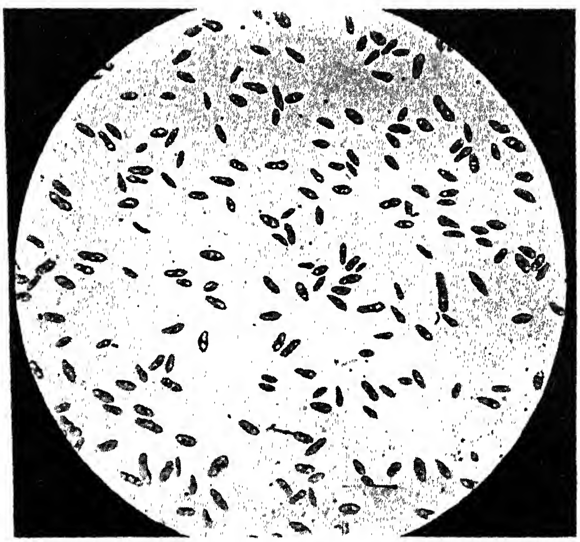


FIG. 18—Typical group of spores produced by *Polyspora Lini* (x 300). The spores are of more irregular shape than in the case of *C. linicola* and their size ranges from 9-20μ x 3-5μ.

RUST

(*Melampsora Lini* (Ehrenb.) Lév.)

General

Rust is a disease of flax caused by the fungus *Melampsora Lini* (Ehrenb.) Lév. which has been reported from almost every country where the crop is grown for fibre or linseed.

The phase of the disease to which the term " rust " is commonly applied is characterised by the appearance in early summer of small yellow or orange coloured pustules on the leaves, stems and parts of the flower (Figs. 19-20). The pustule is the site of production of innumerable summer spores (uredospores) each of which is orange coloured and borne on a separate stalk (Figs. 21-23). When ripe the spores become detached and are so readily dispersed by wind and air currents that those produced from any one crop may spread over a wide territory in a short space of time. When it is realised that every spore under proper conditions is capable of immediate germination and that each is also capable of producing a fresh infection if it alights on a susceptible portion of a flax plant, then it is seen how effective the summer spores can be in spreading the disease throughout the crop.

Later in the growing season elongated, slightly raised, black incrustations appear on the main stem, branches, leaves and seed bolls on the sites occupied by the pustules producing summer spores (Fig. 24). These incrustations are made up of winter spores (teleutospores) of the fungus which are arranged as a compact palisade like layer encrusting the affected portion of the plant (Fig. 25). It is the occurrence of these spectacular black streaks resembling burnt patches on the stems and boughs that led to the popular name of " firing " for this phase of the disease. The winter spores are thick walled and resistant ; they are not capable of immediate germination and normally serve to carry the fungus alive over the winter. Although it is usual for them to germinate in the spring or early summer following their production, under certain conditions they may survive at least two winters. When a winter spore germinates it produces four smaller pear shaped thin walled spores (basidiospores) ; these become detached from the parent spore and if contact with a flax plant is made, each is capable of immediate germination and causing infection. The winter spore is, therefore, the natural agent whereby the rust fungus survives the winter and is enabled to re-infect the next season's crop.

Infection through the agency of the winter spore does not, in the first place, result in the production of rust pustules with summer spores. Such infection gives rise to the production of tiny flask shaped structures (spermogonia) which are invisible to the naked eye and are embedded in the tissues of the affected leaf. Each spermogonium contains a large number of minute spores (spermatia) which are eventually extruded through an opening in the small beak or neck of the flask and thereby

reach the outside of the plant. The spermogonia with their spermatia are important in so far as they may possibly provide for the sexual reproduction of the fungus whereby new strains of the parasite capable of attacking different varieties of flax may arise.

The next stage in the development of the fungus occurs in the immediate neighbourhood of the spermogonia. This takes the form of a tiny raised pustule (aecidium) produced immediately below the skin (epidermis) of the leaf. In this pustule chains of spores (aecidiospores) are produced which are eventually set free by the rupture of the leaf skin covering them. These spores become dispersed and those which successfully germinate and set up infection give rise to the first batch of rust pustules producing summer spores (uredospores) of the season. Thus the life history of the fungus is completed. The aecidia which follow the formation of spermogonia are also yellow and appear before the rust pustules but as only very few of them are frequently produced, they usually escape recognition and their identity is soon lost among the countless rust pustules which develop and cover the crop when once a rust epidemic gets under way.

The summer spores (uredospores) and aecidiospores are normally short lived and cannot survive the winter apart from the growing plant so that under conditions where only the spring sowing of flax is practised and where volunteer (self sown) plants cannot survive the winter, the winter spores provide the only means whereby the fungus can be carried over alive from season to season. In those countries, however, where both the spring and autumn sowing of flax is practised and under the conditions of an open winter where volunteer plants can survive, the summer spores may be the means of carrying the fungus over from year to year in which cases the winter spores may not be necessary to ensure its survival. Very high temperatures are known to exert an adverse effect on the winter spores (teleutospores) which lose their vitality if exposed to high temperatures after harvest. Under such conditions the aecidial stage will be absent in nature and when it is realised that the uredospores also cannot withstand high summer temperatures, the occurrence of rust epidemics in regions where such temperature conditions occur is best explained by the carriage of viable summer spores by air currents from other districts.

Although a slight attack of rust may have little effect upon the crop, a heavy attack frequently results in defoliation of the plants and the general vigour of the crop is adversely affected. The formation of incrustations of the black winter spore stage upon the main stems tends to weaken the fibres at the points of attack with the result that breaking occurs during scutching and there is a consequent loss of long fibre. In addition, portions of the black fungus crusts may remain attached to the fibre even after retting and scutching have been carried out so that they find their way into the yarn and become incorporated into the cloth where they appear as black unsightly spots (Fig. 26).

The fungus is normally carried with the seed rather than on the seed. In seed processing, small fragments of stem, leaves and bolls bearing

fragments of the winter spore stage may be left in the seed sample after it has been finally cleaned and this is the principal method by which the disease is spread by the winter spores from season to season. Some of these fragments may adhere to the seed. The winter spores are thus sown with the seed and germinate in close proximity to the growing plants so that the conditions are eminently suitable for bringing about infection of the crop.

Experimental work carried out in America, Australia, Germany and Russia has shown that all varieties of flax do not react similarly to infection with rust. On the whole the greatest variation in susceptibility to the disease is found in the oil or seed producing varieties some of which are entirely resistant, whereas resistance to such an extent is seldom found among the varieties grown for fibre. It has also been demonstrated that a number of distinct strains of the rust fungus exist and different varieties of flax are known to vary in their response to attack by different strains of the parasite. As these different strains of the fungus may occur in different flax growing countries it follows, therefore, that a variety of flax which shows resistance in one country may prove susceptible when grown in another. Likewise, there is the danger of new strains of the fungus appearing which may have the power to attack varieties of flax which have hitherto proved resistant. The factors which confer resistance to rust upon certain flax varieties are not properly understood but evidence has been produced to show that such characters as thickness or toughness of the epidermis and the stomatal mechanism may operate in determining resistance or susceptibility.

Recently, a disease known as " false " browning (q.v.) has been recorded in flax crops in Victoria, Australia. This disease is associated with a heavy infection of immature, abortive rust (uredospore) pustules. In some ways the symptoms resemble those of browning but the coloration exhibited by infected plants is brick red and not dark brown while the disease lesions formed are also atypical. The organism responsible for browning (*Polyspora Lini*) has on no occasion been isolated from plants affected with " false " browning. The disease occurred in Australia in each of the three seasons 1942-1944 and was always recorded about one week after sudden hot spells when shade temperatures exceeded 80° F. So far the disease has not been recorded outside Australia.

Prevention and Control

As there is no evidence to show that seed disinfection will either kill or prevent the winter spores from germinating, this control measure cannot be recommended for flax rust. In order to prevent rust from being carried over with the seed the greatest care should be taken to remove all crop fragments which may occur as impurities in bulks of seed to be used for sowing. If at all practicable, seed from heavily affected crops should not be sown but should be used for crushing or feeding. Every care should be taken to prevent all flax debris and by-products from factories processing crops affected with rust, from finding their way back to land

in or near which it is intended to grow flax immediately. The chances of rust attack will also be lessened if a wide rotation is followed and flax is not grown in the same land more than once in six or seven years. Any measure adopted to destroy or discourage the growth of volunteer plants likely to contract the disease and survive the winter will assist in preventing the disease from being carried over in this manner. Rust is generally most serious in late sown crops so that early sowing is to be strongly recommended as a means for avoiding attack. Accumulated evidence indicates that the disease is much worse in crops making soft and luxuriant growth due to their being grown in too rich soil ; in districts where rust is prevalent the growing of flax on rich lea ground should not be encouraged. In view of the fact that there are differences between the strains of the rust fungus occurring in different countries, the prevention of the introduction of new strains of the parasite from abroad through the agency of seed is a matter deserving consideration.

Field trials made in Northern Ireland with a number of fibre varieties raised in the U.S.S.R. and claimed to be resistant to rust, have confirmed their immunity to the disease.

It was suggested in the United States that the application of agricultural borax to the soil either prevents infection or greatly reduces the incidence of rust. This claim has not been supported by further trials carried out elsewhere in the United States and in Northern Ireland.

REFERENCES

Allen, R. F. (1934). A cytological study of heterothallism in flax rust. J. agric. Res. 49, 765-791.

Cass-Smith, W. P. (1942). Flax rust. J. Dep. Agric. West Aust. 1, 2nd Ser. 56-63.

Colhoun, J. (1945). The effect of boron on the development of flax rust. Gdns'. Chron. 118, 191.

Flor, H. H. (1935). Physiologic specialization of *Melampsora Lini* **on** *Linum usitatissimum.* **J. agric. Res. 51, 819-837.**

Flor, H. H. (1940). New physiologic races of flax rust. J. agric. Res. 60, 575-591.

Flor, H. H. (1941). Pathogenicity of aeciospores obtained by selfing and crossing known physiologic races of *Melampsora Lini.* Phytopathology, 31, 852-854.

Flor, H. H. (1942). Inheritance of pathogenicity in *Melampsora Lini.* Phytopathology, 32, 653-669.

Flor. H. H. (1946). Genetics of pathogenicity in *Melampsora Lini.* J. agric. Res. 73. 335—357.

Flor, H. H. (1947). Inheritance of reaction to rust in flax. J. agric. Res. 74, 241—262.

Hart, H. (1926). Factors affecting the development of flax rust, *Melampsora Lini* **(Pers.) Lév. Phytopathology, 16, 185-205.**

Hart, H., Mitchell, J. E., & Gottlieb, D. (1943). Boron soil treatment and the development of flax diseases. Phytopathology, 33, 1113.

Heggeness, H. G. (1942). Effect of borax applications on the incidence of rust on flax. Plant Physiol. 17, 143-144.

Henry, A. W. (1930). Inheritance of immunity from flax rust. Phytopathology, 20, 707-721.

Millikan, C. R. (1945). A " False " browning reaction to rust (*Melampsora Lini*) infection in flax. J. Agric. Victoria, Feb. 1945, 83-92.

Pethybridge, G. H. & Lafferty, H. A. (1920). Investigations on flax diseases. J. Dep. Agric. Ire. 20, 325-342.

Pethybridge, G. H., Lafferty, H. A. & Rhynehart, J. G. (1921). Investigations on flax diseases. J. Dep. Agric. Ire. 21, 167-187.

Prasada, R. (1940). Aecidial-stage of the rust of linseed. Curr. Sci. 9, 328-9.

Sharvelle, E. G. (1936). The nature of resistance of flax to *Melampsora Lini*. J. agric. Res. 53, 81-127.

Straib, W. (1939). Zum epidemischen Auftreten des Leinrostes in Ostpreussen. NachrBl. dtsch. PflSchDienst. 19, 49-51.

Straib, W. (1939). Untersuchungen über den Wirtsbereich und die Aggressivität physiologischer Rassen von *Melampsora Lini*. Züchter, 11, 130-136, 162-168.

Straib, W. (1942). Beiträge zur Epidemiologie und Bekämpfung des Flachsrostes. Angew. Bot. 24, 16-30.

Vallega, J. (1938). Observaciones sobre la resistencia a la roya de algunos Linos ensayados en el Instituto Fitotecnico de Llavallol. Rev. argent. Agron. 5, 25-56.

Waterhouse, W. L. & Watson, I. A. (1941). A note on determinations of physiological specialisation in flax rust. J. roy. Soc. N.S.W. 75, 115-117.

Waterhouse, W. L. & Watson, I. A. (1944). Further determinations of specialisation in flax rust caused by *Melampsora Lini* (Pers.) Lév. J. roy. Soc. N.S.W. 77, 138-144.

FIG. 19—Portion of flax plant showing infection with the summer stage (uredosori) of flax rust.

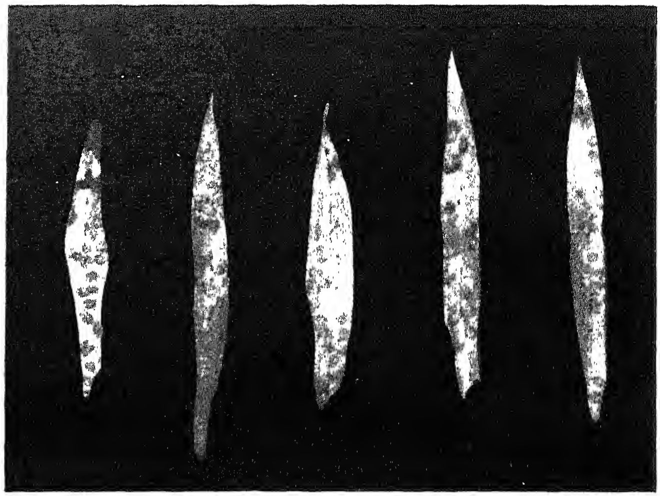


FIG. 20—Individual leaves showing the summer stage (uredosori) of rust (slightly enlarged).

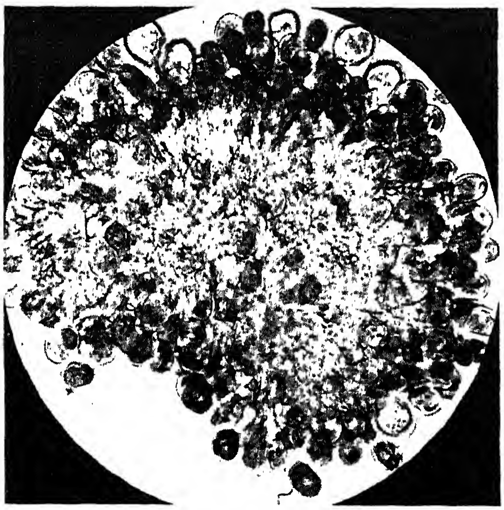


FIG. 21—Crushed uredosorus showing the production of uredospores (summer spores) (x 300).

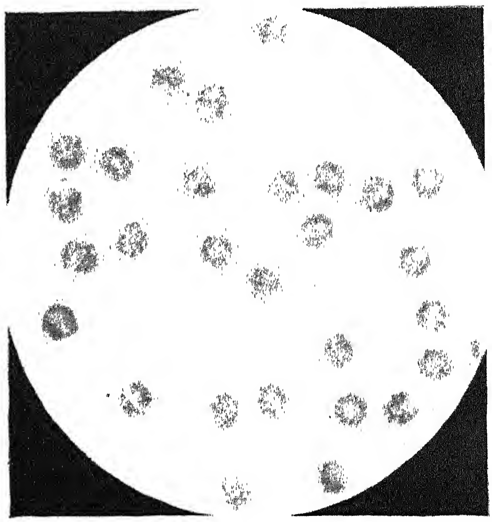


FIG. 22—Summer spores (uredospores) mounted in water (x 300).

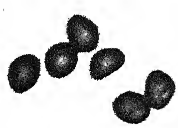


FIG. 23—Summer spores (mounted dry) to show the echinulations of the spore coat (x 300).

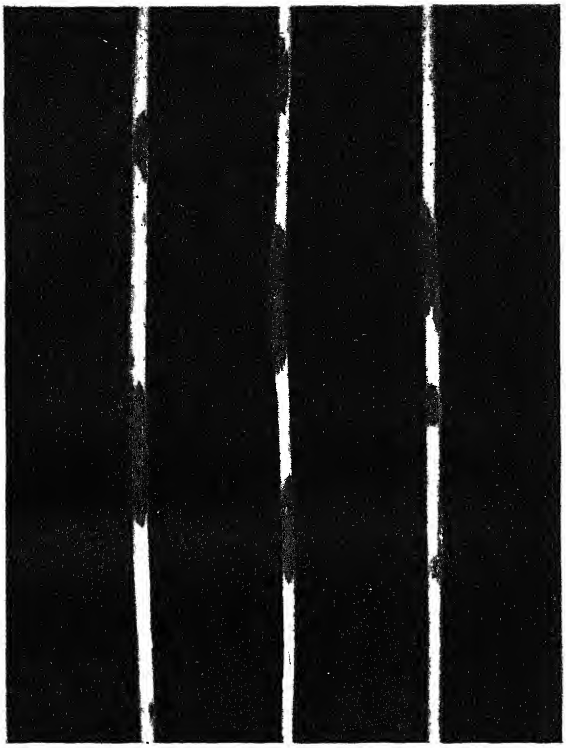


FIG. 24—Flax straws affected with " Firing," the winter stage (teleutosori) of rust.

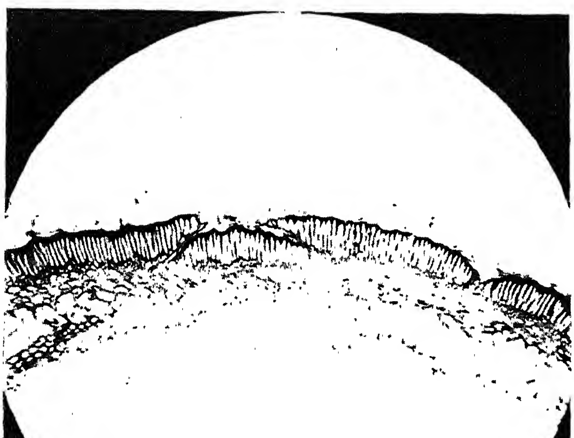


FIG. 25—Section through a teleutosorus showing the palisade-like arrangement of the spores (x 65).

FIG. 26—Scutched fibre blemished by the black incrustations of the winter stage (" Firing ") of rust.

WILT

(*Fusarium Lini* Bolley)

General

Flax wilt is caused by the fungus *Fusarium Lini* Bolley ; the disease occurs in nearly all countries where the crop is grown and the condition of " soil sickness," as it applies to flax cultivation, is normally brought about by the soil having become heavily contaminated with the causal parasite of this disease. Although *Fusarium Lini* is the fungus commonly responsible for wilt, it is not unlikely that other species of *Fusarium* may on occasion be involved.

The symptoms shown by an affected plant are typical of those generally ascribed to wilt diseases and the attack may take place at any time during the growth of the crop from the seedling stage to that of approaching maturity. In the case of the seedling, growth ceases soon after the plant has become attacked when the leaves and stem die, turn brown and shrivel from the crown downwards. The dead plant remains erect for some time and usually stays so until it is destroyed by general decay. The attack may not be general and those plants which are unaffected rapidly outgrow the remainder so that, if the proportion of infected plants is small, the dead seedlings may escape detection. Plants infected at a later stage also die from the top downwards (Fig. 27) ; the first symptoms are shown by the tendency of the plant to droop and this is followed by the death and shrivelling of the leaves around the growing point of the stem. As the attack develops, the lower leaves die and come to lie along the stem so that the plant assumes the top heavy appearance of a tufted crown of dead or dying leaves surmounted on a thin stem. Infection contracted when the crop is reaching maturity is not so readily recognised owing to the general cessation of growth in height of the plants and the onset of ripening. It is not until the plant has been killed and the straw has turned brown that a satisfactory diagnosis can be made in the field. Moreover, at this stage of crop development, plants affected by other diseases and, in particular, by foot rot (q.v.) may present a somewhat similar appearance. In such cases it is necessary to examine carefully the stem bases of affected plants. If the disease is wilt, creamy white pustules of the fungus may frequently be observed in this region of the stem (Fig. 28). These pustules or sporodochia constitute the reproductive stage of the fungus, and, if examined microscopically, each will be found to consist of a very large number of multicellular sickle-shaped colourless spores produced from a minute cushion of fungus threads formed at the surface of a diseased straw (Fig. 30). If it is foot rot, a large number of the small dark coloured spore containers of *Phoma*, the fungus responsible for this disease, will be found. In cases where neither of these symptoms occur it is desirable to submit the plant to a laboratory examination before a diagnosis is made. The general symptoms of wilt resemble those which would be produced in a plant from which water is withheld but whether the wilting results from a simple stoppage in the water supply, through

the destruction of the root hair system or from a more complex cause such as poisoning by the production of toxic substances by the fungus growing within the conducting tissues of the plant, has yet to be properly explained.

From the foregoing it will be deduced that the flax wilt organism is carried by the soil and this is usually the case. The fungus may persist in the soil for many years in the absence of a flax crop but the more frequently the crop is grown in contaminated soil the greater will be the risk of a severe attack providing the conditions for attack are suitable. No plant other than flax has been shown to be capable of becoming infected by this particular parasite. The spread of the fungus to clean land may occur through the carriage of contaminated soil or the debris from an affected crop ; it may also occur through the sowing of contaminated seed.

Loss of crop due to the incidence of wilt may be negligible or complete according to the circumstances of the attack. The whole crop may be destroyed at any stage in its development or the attack may be confined to individual plants or groups of plants here and there in the crop ; such plants are commonly referred to as "dead stalks," a term popularly applied to odd plants which have been killed by wilt or some other disease during the growing season.

Flax wilt constitutes an excellent example of a crop disease the incidence of which is largely dependent upon the conditions under which the crop is grown ; the main factor concerned is soil temperature with the soil moisture content as a subsidiary. The contamination of the land with the parasite is not sufficient to ensure an attack and a comparatively high soil temperature must be attained at some time during the growing season to provide suitable conditions for the attack to develop. The minimum critical soil temperature which is necessary is approximately 14°C. (57°F.), the optimum 24-28°C. (79°F.) and the maximum 34-38°C. (97°F.). These conditions apply to the top 5 in. (12.5 cm.) of the soil where the fungus is found in greatest concentration. The necessity for these conditions of soil temperature to be fulfilled for a certain period during the growing season accounts for the varying extent of the attack from season to season in temperate regions with a changeable climate. It also accounts for the different times during the growing season at which the disease may make its appearance. If at the time of attack a period of drought occurs and the soil becomes dry the disease assumes more serious proportions than under damp, warm conditions. In countries where high soil temperatures are regularly experienced during the growing season the disease may be epidemic each year when once the land has become inoculated with the responsible parasite.

Prevention and Control

The flax wilt organism may be spread through the agency of contaminated seed. During the very extensive examination of United Kingdom flax seed for the presence of seed-borne parasites, which has

been made in recent years, this organism has been but rarely met with as a seed contaminant, and the infrequency of its occurrence indicates that this method of spread is not of great importance in the United Kingdom under present day conditions. The efficiency of modern seed disinfectants has not been investigated because no seed samples suitable for experimental work have been encountered, although, there is reason to believe that such treatment should rid the seed of the parasite for, in the United States, where seed contamination would appear to be of some consequence, the treatment of the seed with a dilute solution of formaldehyde is recommended as effective.

Debris from an infected crop may constitute a real danger in the spread of the parasite to adjacent lands and every care should be taken to avoid the contamination of land by this means. At the same time the debris from such a crop will increase the infective power in the land on which the crop is grown, and, this being so, a sufficiently long crop rotation should be practised so that flax will not be grown in such land more frequently than, say, once in seven years.

Attempts to rid the soil of the parasite by the use of chemical substances applied as disinfectants or fertilizers have been made in more than one flax growing country including Northern Ireland, but, up to the present, no treatment of this kind, which can be regarded as both effective and economical on a farm scale, has been found.

In countries where wilt is known to occur and where flax has been grown for generations in spite of the disease, it is probable that the contamination of the land with the parasite is fairly general. In other words, climatic conditions have operated as the most important controlling factor and have prevented the disease from becoming generally epidemic. This would appear to be the case in Northern Ireland where the organism has frequently been isolated from land carrying a crop almost entirely unaffected with the disease. Under conditions where the climate is cool and moist the tendency for the crop to contract epidemic infection will depend to a large extent upon the soil type. For instance, where the soil is on the heavy side and the sub-soil of clay and cool, the crop may be grown without fear of serious wilt infection, but where it is light and gravelly and the sub-soil warm the disease may, on occasions, become epidemic and cause a total loss of crop. So variable may the soil configuration be in Northern Ireland that conditions may change from field to field and on certain farms one or more fields may be earmarked as likely to produce seriously wilted crops if flax is grown in them.

In practice, flax wilt has been most successfully overcome by the breeding and propagating of resistant varieties which yield the normal quantity of the economic product and at the same time, withstand attack by the disease. The linseed industry of the United States was faced with extinction during the early years of the present century owing to the rapid spread of wilt. It was saved by the building up of strains of linseed flax from selected plants which showed marked resistance to the disease.

Comprehensive trials carried out in Northern Ireland have given the following results for the reaction of flax varieties to wilt attack (Fig. 31). The only variety found to be immune is Redwing, an oil producing type from the United States ; Norfolk Queen, Pinnacle, and Stormont Cirrus are fibre producing varieties which are highly resistant while Dutch H., J.W.S., Herkules, Blenda and Linkopis are intermediate in their reactions and show some seasonal variation. Liral Crown, Stormont Gossamer and Liral Prince are susceptible while Concurrent, Liral Monarch, Blue Star and Liral Dominion are all very susceptible to attack.

REFERENCES

Barker, H. D. (1923). A study of wilt resistance in flax. Min. agric. Exp. Sta. Tech. Bull. 20.

Baylis, G. T. S. (1940). Flax wilt (*Fusarium Lini*) in New Zealand. N.Z.J. Sci. 22, 157A-162A.

Bolley, H. L. (1901). Flax wilt and flax sick soil. N. Dak. agric. Exp. Sta. Bull. 50.

Boyle, L. W. (1934). Histological characters of flax roots in relation to resistance to wilt and root rot. U.S. Dept. Agric. Tech. Bull. No. 458.

Broadfoot, W. C. (1926). Studies on the parasitism of *Fusarium Lini* Bolley. Phytopathology, 16, 951-978.

Burnham, C. R. (1932). The inheritance of *Fusarium* wilt resistance in flax. J. Amer. Soc. Agron. 24, 734-748.

Flor, H. H. (1940). Soil sickness of flax in North Dakota. Phytopathology, 30, 749-760.

Jones, L. R. & Tisdale, W. B. (1922). The influence of soil temperature upon the development of flax wilt. Phytopathology, 12, 409-413.

Millikan, C. R. (1945). Wilt disease of flax. J. Dep. Agric. Vict. 43, 305-313, 354-361.

Nelson, C. I. & Dworak, M. (1926). Studies on the nature of wilt resistance in flax. N. Dak. agric. Exp. Sta. Bull. 202.

Pethybridge, G. H., Lafferty, H. A. & Rhynehart, J. G. (1921). Investigations on flax diseases. J. Dep. Agric. Ire. 21, 167-187.

Schuster, M. (1944). The nature of resistance of flax to *Fusarium Lini*. Phytopathology, 34, 356.

Tisdale, W. H. (1917). Flaxwilt : a study of the nature and inheritance of wilt resistance. J. agric. Res. 11, 573-605.

Tisdale, W. H. (1917). Relation of temperature to the growth and infecting power o *Fusarium Lini*. Phytopathology, 7, 356-360.

Tochinai, Y. (1925). Comparative studies on the physiology of *Fusarium Lini* and *Colletotrichum Lini*. J. Coll. Agric. Sapparo, 14, 171-236.

Wilson, I. M. (1946). Observations on wilt disease of flax. Trans. Brit. mycol. Soc. 29, 221-231.

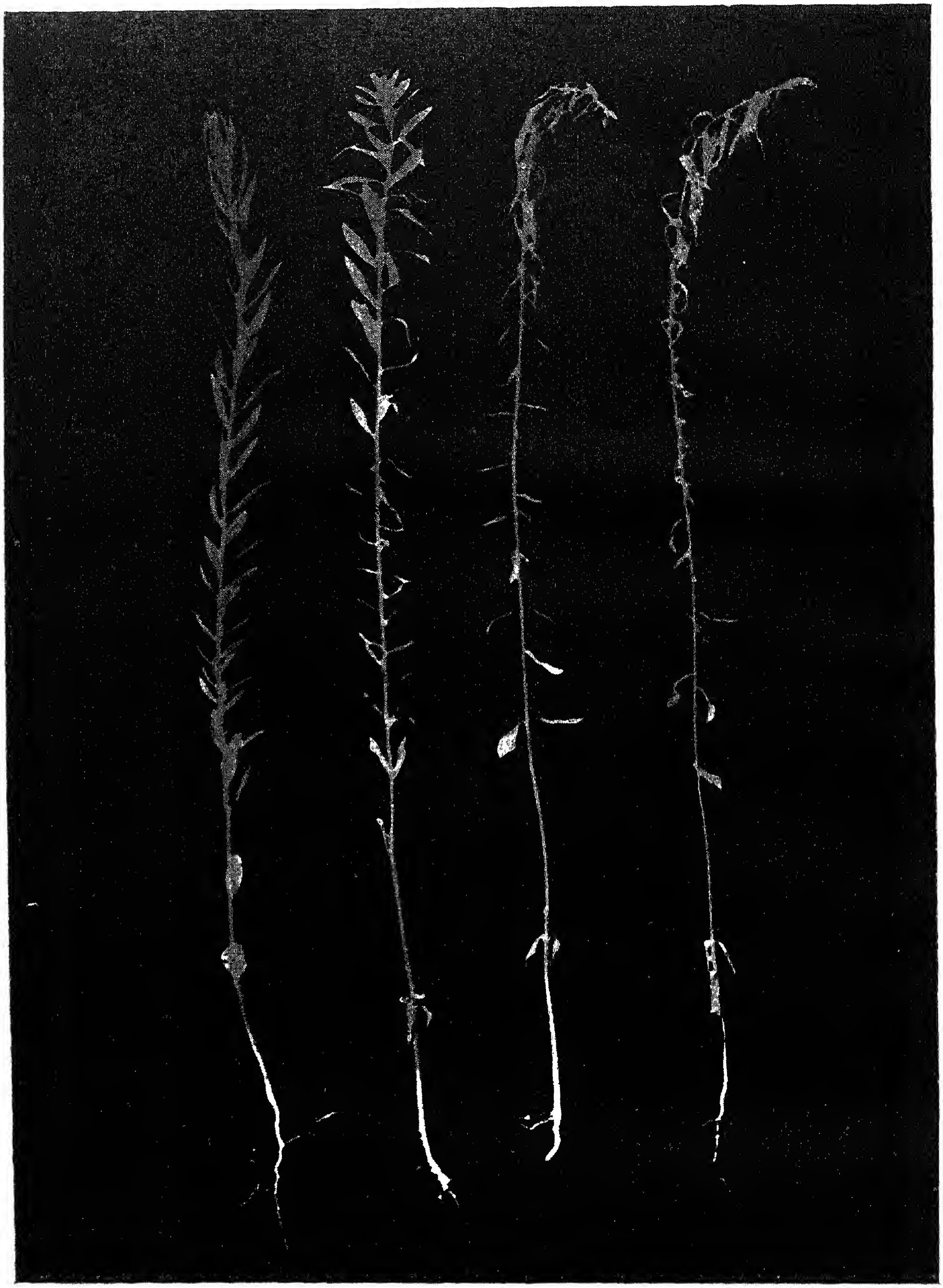


FIG. 27—Flax plants showing the typical symptoms of attack by wilt (*Fusarium Lini*). The specimen on the left is healthy while the three to the right illustrate the progressive stages of the disease culminating in the death of the plant.

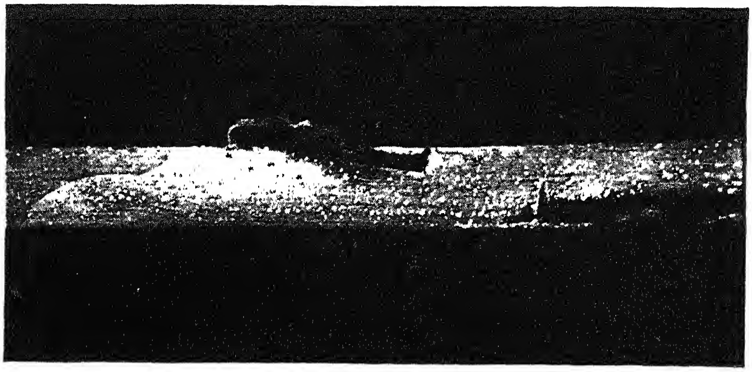


FIG. 28—Portion of a flax straw affected with wilt and showing the production of spore bearing pustules (sporodochia) of the fungus (x 7).

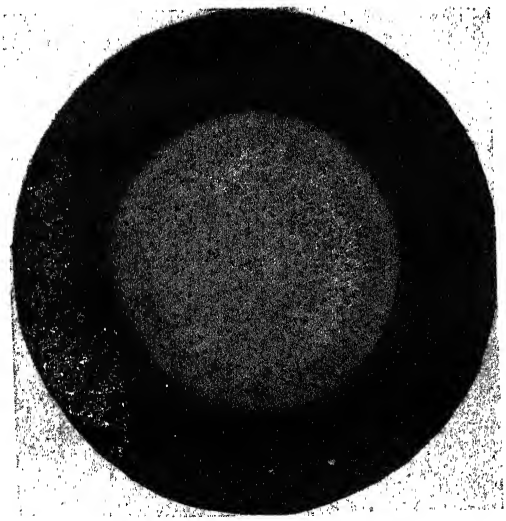


FIG. 29—A typical colony of *Fusarium Lini* growing on 2 per cent. malt agar.

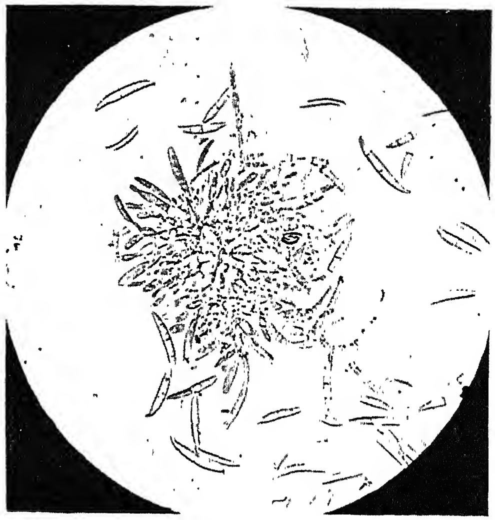


FIG. 30—A crushed spore producing pustule (sporodochium) and a group of the typical sickle shaped spores produced by *Fusarium Lini* (x 300). The spores are normally four celled and the actual spore size ranges from 28-32μ x 2.9-3.6μ.

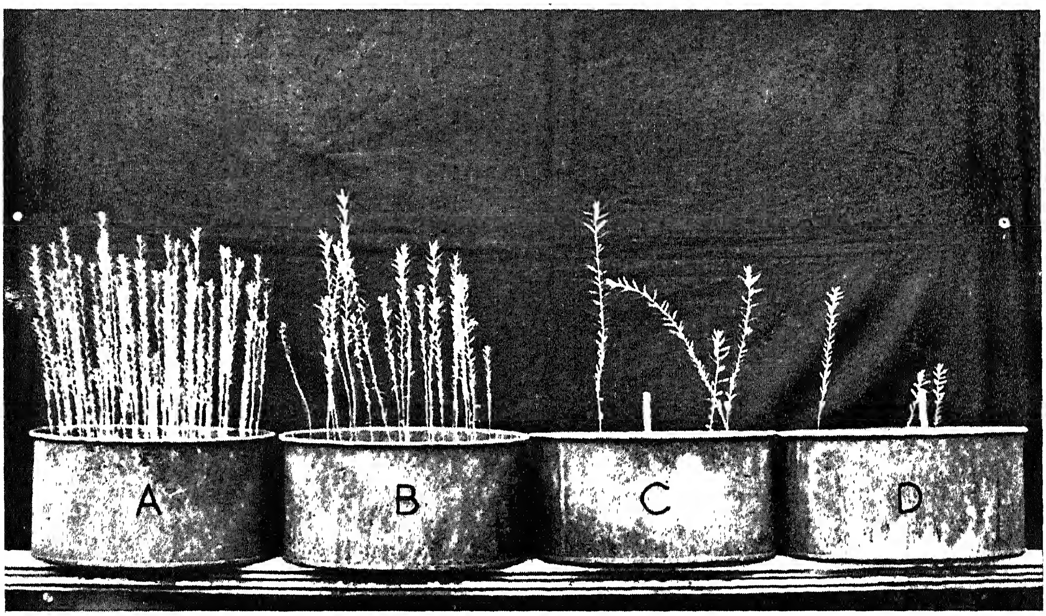


FIG. 31—A typical group of pots taken from greenhouse trials made with the object of determining the susceptibility or resistance of flax varieties to attack by wilt.

A—Norfolk Queen ; B.—Stormont Cirrus. C—-Liral Prince. D.—Liral Crown.

FOOT ROT

(*Phoma* sp.)

General

Foot rot of flax is known to occur in Austria, the British Isles, Esthonia, France, Germany, Holland, Hungary, Latvia, Spain and the U.S.S.R. In the British Isles the disease has been proved to be caused by a species of *Phoma* which investigators have preferred to leave unnamed. In Europe a number of named species of *Phoma* such as *P. exigua*, *P. herbarum*, *P. Lini* and *P. linicola* have been blamed for the disease and species of *Ascochyta* have also been held responsible but it is evident from the literature that the position is anything but clear and that the problem requires much further elucidation. In the experience of the writers the position in the British Isles would not seem to be unduly complicated and they are of the opinion that the unnamed species of *Phoma* isolated from various sources in these islands and used in the Northern Ireland investigations, is the organism responsible for the disease in every case which has come to their notice. Another species of *Phoma* and a species of *Ascochyta* isolated from flax seed have been investigated in Northern Ireland but these fungi do not appear to be associated with foot rot disease.

It is believed that the fungus responsible for foot rot is present in soil and that the disease is first contracted from the soil. In this case the disease is not likely to be serious and normally takes the form of an occasional affected plant found here and there in the crop. Such outbreaks are not usually of importance and here foot rot, taken together with a number of other minor diseases of the crop, gives rise to a condition known as " dead stalks." Seed saved from crops which have become affected in this manner may be contaminated with the parasite, and when the percentage of such contamination is heavy, the disease may become epidemic and grave crop losses may result from its use. Thus, while foot rot contracted from the soil may be of little importance its contraction through the agency of contaminated seed may have serious consequences. The parasitic fungus is carried by the seed in the usual manner and its presence as mycelium in the outer layers of the seed coat is of much greater significance than the presence of spores carried on the seed surface.

The crop may be attacked in the early stages of growth when the seedlings are rapidly killed within a few weeks of brairding. The attacked seedlings become yellowish in colour and exhibit wilting in the early stages (Fig. 32). The collar of the plant at soil level and the roots become brownish in colour. When the plants have been killed large numbers of minute spore bearing bodies are produced by the fungus on the dead plant portions above ground (Figs. 34-35). These bodies, which are known as pycnidia, are almost sphaerical and resemble tiny flasks with short blunt necks (Fig. 36). They are dark in colour and are embedded in the outer tissues of the stem, their blunt necks reaching and often slightly pro-

truding beyond the surface. When ripe each contains a very large number of microscopic colourless unicellular spores (Fig. 39) which are extruded through an opening or ostiole (Fig. 36) in the neck of the flask in the form of a yellowish curved tendril (Fig. 37). A small proportion of the spores may be bicellular or two-celled. The spores are capable of immediate germination and growth and thus provide an effective method by which the fungus may be spread during the summer.

The seedling stage of the disease is frequently unimportant and may escape notice in the field. Foot rot as such does not usually become evident until the time of flowering when affected plants exhibit conspicuous wilting and assume a yellowish colour. At the foot of an affected plant a pale brownish area is observed and in most cases the roots will also show a brownish discolouration. The epidermis or skin becomes readily detached from the diseased stem and the foot of the plant takes on a ragged appearance. Pycnidia are formed in abundance (Figs. 34-35) and ultimately the plant is killed. The dead plants remain erect and on account of their general appearance and brown colour can readily be distinguished from their greener and healthy neighbours (Fig. 33). When the attack assumes epidemic proportions and the healthy plants are but few, the crop presents a distressing sight and may become an almost total loss.

In Australia, a disease caused through attack by a species of *Phoma* has been recorded where dark brown spots are produced on the stem of the plant ; the upper part of the stem may be killed while the basal portion appears quite normal. In the U.S.S.R. a somewhat similar disease, due to a species of *Phoma*, has been described where the fungus attacks the middle and apical portions of the stem which is neither discoloured nor killed. It is not clear whether these diseases are different from or are phases of that occurring in the British Isles.

Prevention and Control

Inasmuch as the disease may be contracted by growing crops in contaminated soil, flax should not be sown too frequently in the same land. Care should be taken to prevent flax straw detritus from reaching land in which it is proposed to grow flax during the next few years.

In so far as the parasite is seed-borne, no disinfectant has yet been found which is capable of bringing about the complete control of foot rot. Partial control is obtained by seed disinfection with " Nomersan " or " Arasan " used at the rate of 12 oz. per cwt. and applied by the dusting method or with an 8 per cent. solution of " Ceresan U.564 " used at the rate of 0.9 gall. per cwt. of seed and applied by the short wet method. Seed contaminated to a greater extent than 5 per cent. should be discarded and not sown, while seed contaminated to the extent of 5 per cent. or less should be disinfected before sowing. It should also be remembered that the repeated use of seed saved from the same stock may lead to a gradual build up of percentage contamination if the growing seasons favour the incidence and development of the disease. For this reason it may be

desirable to ensure the income of fresh stocks of non-contaminated seed at regular intervals for growing in districts where climatic conditions encourage foot rot. Little is yet known regarding the reactions of flax varieties to this disease under different sets of climatic conditions. Observations made in Northern Ireland indicate that while none of the varieties tested have shown immunity, a considerable measure of resistance has been shown by the two oil varieties, Hindi and La Plata. No fibre producing variety has yet been found to possess marked powers of resistance.

The control of the disease by storage of the seed until the parasite has lost its viability is not practicable as unpublished work has shown that the fungus can remain viable on seed for a period of more than three years.

REFERENCES

Marchal, P. & Foex, E. (1927). Rapport phytopathologique pour les années 1926-1927. Ann. des Épiphyties, 13, 383-454.

Marchal, E. & Verplancke, G. (1926). Champignons parasites nouveaux pour la Flore Belge observés de 1919 à 1925. Bull. Soc. roy. Bot. Belg. 59, 19-25.

Millikan, C. R. (1944). *Phoma* stem disease of flax. J. Aust. Inst. agric. Sci. 10, 129-130.

Muskett, A. E. & Colhoun, J. (1945). Foot rot (*Phoma* sp.) of flax. Nature, Lond., 155, 367.

Muskett, A. E. & Colhoun, J. (1945). Control of foot rot (*Phoma* sp.) of flax. Nature, Lond., 156, 538.

Naoumoff, N. A. (1926). Novelties of the local mycoflora. Mycology. Leningrad 1.

Pethybridge, G. H., Lafferty, H. A. & Rhynehart, J. G. (1921). Investigations on flax diseases. J. Dep. Agric. Ire. 21, 167-187.

Rost, H. (1938). Untersuchungen über einige Krankheiten des Leins in Deutschland. Angew. Bot. 20, 412-430.

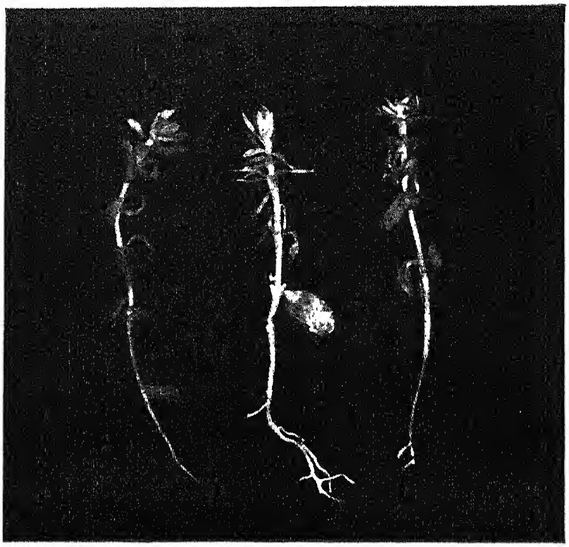


FIG. 32—Young flax plants showing typical symptoms of attack by *Phoma* sp. the organism responsible for foot rot. Such plants will not recover.

FIG. 33—Two pots of flax plants showing the effect of a severe attack of foot rot. The pot on the left shows flax plants grown from non-contaminated seed sown in sterilised soil while that on the right shows plants grown under exactly the same conditions except that the soil in this case was heavily inoculated with a culture of *Phoma* sp. the organism responsible for foot rot.

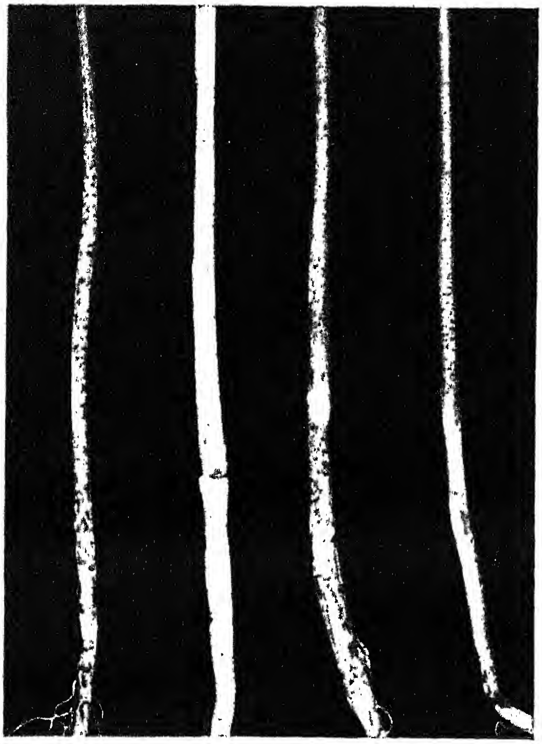


FIG. 34—The basal portions of flax stems attacked and killed by foot rot. The minute spore bearing bodies (pycnidia) are being produced in abundance.

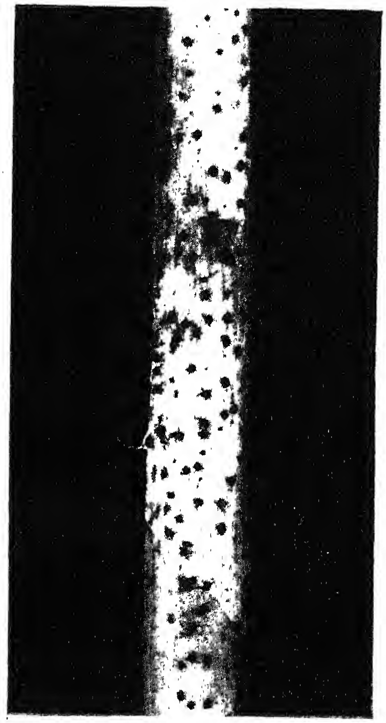


FIG. 35—Portion of a flax straw attacked by foot rot. It is enlarged to show the black pycnidia more clearly (x 8).

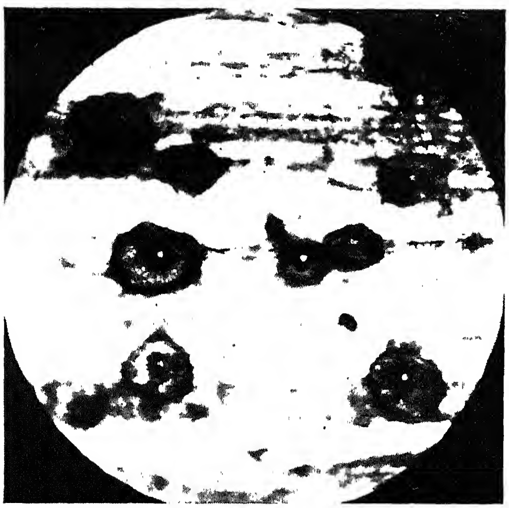


FIG. 36—A group of pycnidia produced on a flax straw and much enlarged to show the general structure and the opening or ostiole through which the spores are extruded (x 65).

FIG. 37—A single pycnidium showing the extrusion of the spores in the form of a curved tendril (x 65).

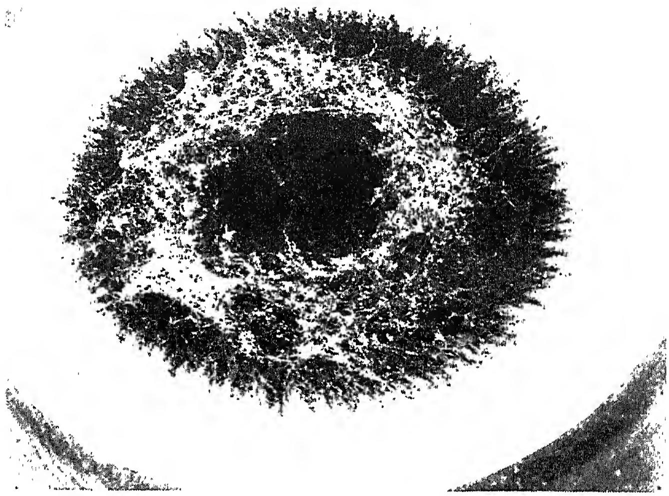


FIG. 38—Typical colony of *Phoma* sp. growing on 2 per cent. malt agar medium.

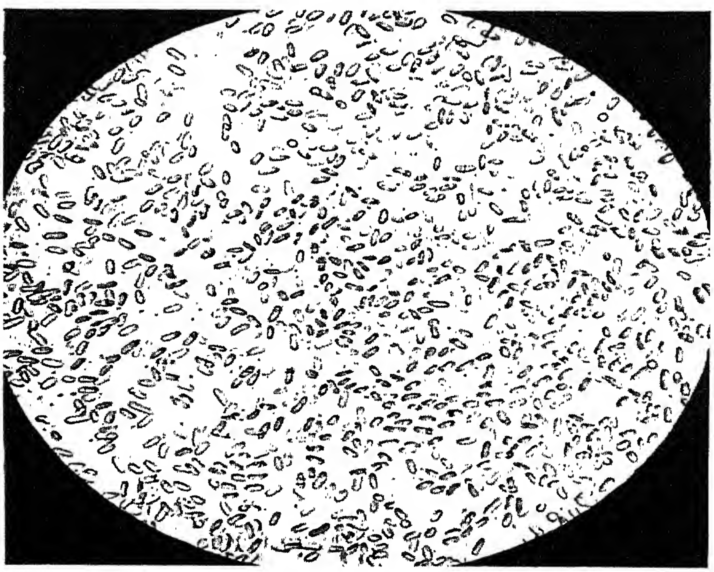


FIG. 39—Group of spores as produced in a pycnidium of *Phoma* sp. (x 300) The actual size of the spore ranges from 3-10μ x 2-3.5μ.

GREY MOULD

(*Botrytis cinerea* Fr.)

General

Grey mould of flax caused by the fungus *Botrytis cinerea* Fr. is known to occur in the British Isles, France, Germany, Holland, Latvia, the U.S.A. and the U.S.S.R. (including Siberia). In Holland the causal organism has been referred to as *Botrytis cinerea* forma *lini.*

Botrytis cinerea is a very widespread parasite of a large variety of plants and also exists as a saprophyte on dead and decaying parts of plants. In the case of flax it is frequently carried by the seed and forms one of the group of seed-borne parasitic fungi. The mycelium is carried in the outer layers of the seed coat and the fungus is capable of attacking flax plants at any stage from the time of the commencement of germination of the seed. The earliest symptoms of attack in a crop may be seen a few days after the appearance of the seed leaves when brownish coloured spots appear on the young stem in the region of the collar at about soil level. The fungus spreads very rapidly and an infected seedling soon wilts, falls over and dies (Fig. 40). At this stage the parasite can be recognised as it grows out from the plant to form a bearded mouldy growth (hence the name—grey mould) the surface of which is dotted with minute groups of colourless unicellular spores which are formed at the tips of the projecting fungus threads and when examined microscopically are seen to assume a " bunch of grapes " formation (Fig. 44). The spread of the fungus is favoured by warm moist conditions and if these prevail shortly after the germination of the seed, infection spreads readily from plant to plant so that groups of seedlings may be killed out in patches. If the conditions are less favourable for the spread of the fungus, isolated seedlings only may be affected. The spread of the disease in a crop may be completely checked by the onset of a cold, dry spell of weather.

In mature plants the fungus usually attacks portions of the stems measuring from half an inch (1.25 cm.) to three inches (7.5 cm.) in length with the result that the attacked stem portion becomes light brown in colour and more or less soft and decayed. The parts of the plant above the infected stem region become yellow and die and this is usually followed by the death of the entire plant. In damp weather the diseased portions of the stems become covered with the typical bearded growth of the fungus as described above in the case of attacked seedlings (Fig. 41).

At a later stage the fungus produces small hard black bodies which are known as sclerotia (Fig. 42) and which, being resistant to adverse growth conditions, serve to carry the fungus alive over periods when the delicate exposed mycelium or spawn would be killed by drought or cold, etc. Observations in America have shown that when the petals of the flowers remain in position after flowering, the fungus becomes established in them and from them invades the bases of the seed bolls from which it can effect an entry and contaminate the seed and also spread down the

branches upon which the bolls are borne. It is also suggested in America that the stem becomes infected through the medium of dead or dying petals which fall on to stems or leaves and in which the fungus first becomes established before proceeding to attack and eventually girdle the stem.

In the case of crops which have become lodged or laid as the result of heavy storms, the laid straws brought into close proximity to the damp soil and enveloped with the rapid growth of weeds and grass, which frequently occurs under such conditions, readily fall victims to grey mould attack. It is here that the disease may cause the greatest damage and render crops completely worthless.

If flax is pulled and tied into beets when damp or if it is pulled dry and stooked but is subject to prolonged wet weather, *B. cinerea* may develop on the stems, foliage and seed bolls. Here it will produce large numbers of spores as well as sclerotia. So it is that grey mould may cause considerable damage to the crop after it has been pulled if the conditions are suitable for its development. The seed may also become contaminated by the fungus under such conditions as well as during the growth of the crop. Contaminated seed may harbour the parasite as mycelium or surface borne spores and, in addition, sclerotia may be formed.

Prevention and Control

B. cinerea as a seed-borne parasite may be controlled by seed disinfection as applied for seedling blight and stem-break and browning. Such treatment will prevent the seedling phase but it will not necessarily control the disease as it occurs in the later stages of the growing and handling of the crop. The fungus may be widespread in nature and infection later in the season may be readily contracted from other sources. Control of the disease in its later phases is difficult and much will depend upon the season as its incidence and spread is encouraged by wet weather with a minimum of air circulating among the plants. Little can be done to prevent the damage caused in lodged or laid crops other than ensuring that the conditions of growth are such as to provide as much as possible against lodging. Such factors as the thickness of sowing, excessive nitrogenous manuring and the choice of variety may all affect the degree of lodging of the crop and should receive special attention. Flax detritus may be the means of encouraging the development and growth of the fungus in the soil so that land intended for a flax crop should be kept free from such contamination.

REFERENCES

Colhoun, J. (1944). Grey Mould (*Botrytis cinerea*) of flax. Nature, Lond., 153, 25-6.

Houston, B. R. (1940). *Botrytis* blight of flax in California. Plant Dis. Reptr. 24, 213-4.

Mackie, W. W. (1940). *Botrytis cinerea* in California flax fields. Plant Dis. Reptr. 24, 214-5.

Pethybridge, G. H. & Lafferty, H. A. (1920). Investigations on flax diseases. J. Dep. Agric. Ire. 20, 325-342.

Rost, H. (1938). Untersuchungen über einige Krankheiten des Leins in Deutschland. Angew. Bot. 20, 412-430.

van Poeteren, N. (1922). Verslag over de Werkzaamheden van den Plantenziektenkundigen Dienst in de Jaren 1920 en 1921. Versl. en Meded. PlZiekt. Dienst Wageningen. 27, 33-36.

FIG. 40—Flax seedlings attacked by grey mould (*Botrytis cinerea*). Note the bearded growth of the fungus on the diseased stems.

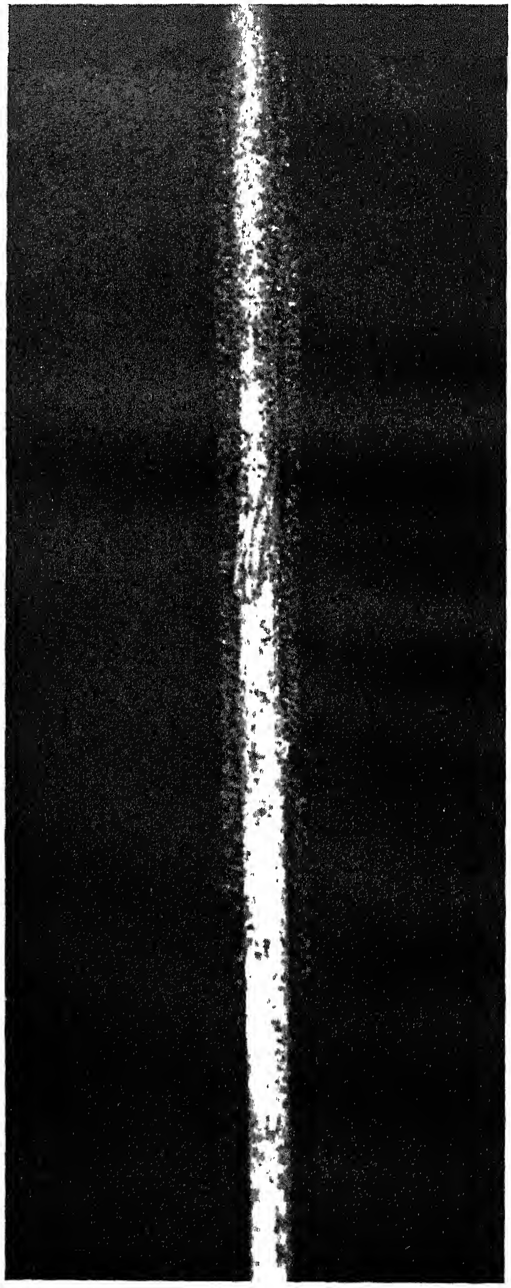


FIG. 41—A flax straw attacked by grey mould. The fungus is producing its typical bearded growth and is sporulating vigorously on the diseased straw. (x 2.5).

FIG. 42—Flax straws with the sclerotia of the grey mould fungus (*B. cinerea*) (x 1.5).

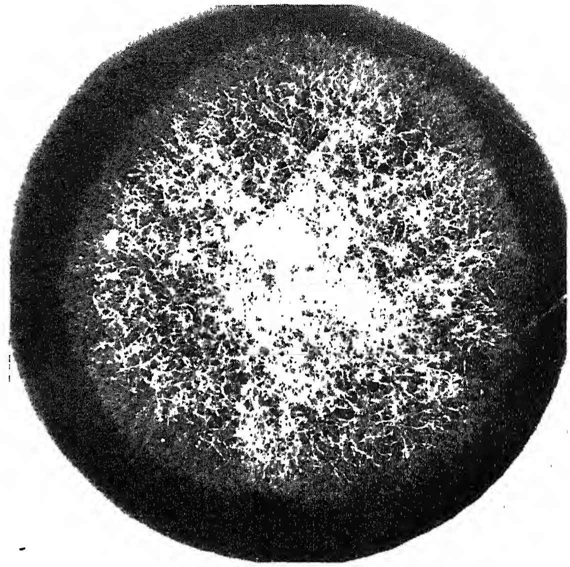


FIG. 43—Typical colony of *Botrytis cinerea* growing on 2 per cent. malt agar.

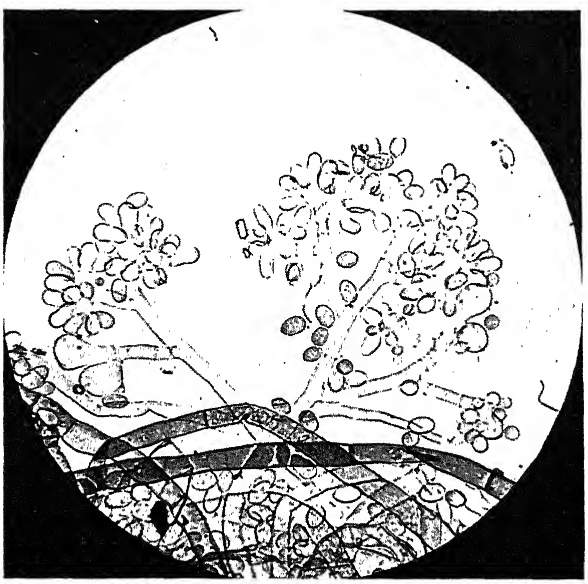


FIG. 44—Typical conidiophores of *B. cinerea* showing the production of the spores and their typical " bunch of grapes " formation (x 300).

POWDERY MILDEW

(*Oidium Lini* Škorić)

General

Powdery mildew of flax is known to occur in Austria, Czechoslovakia, Egypt, England, Germany, Japan, Northern Ireland, Siberia, the U.S.A. the U.S.S.R., Wales and Yugoslavia.

The fungus responsible for this disease has been recorded as a species of *Erysiphe* but owing to the fact that in some countries the life history of the fungus is incomplete, further evidence is desirable before this finding can be accepted generally. The perfect stage of the fungus, which must be found and identified before the fungus can be registered as a species of *Erysiphe*, has not been recorded in the British Isles and for this reason the name of the parasite is referred to as that of its imperfect stage —*Oidium Lini*—the only form in which it has been found.

Infected plants show a profuse development of the mildew on the main stem, on both surfaces of the leaves and on the sepals so that in appearance they would seem to have been dusted with a white floury powder (Figs. 45-46). An examination of the mildew shows that this powder consists of an abundance of microscopic fungus spores (conidia) which have been borne singly or in short chains at the tips of the fungal threads (hypae) and which cover the surfaces of the attacked portions of the plant. Each of these minute spores is capable of immediate growth and it is by their dispersal to healthy plants that the disease is spread in the growing crop. This is the imperfect stage of the fungus known as *Oidium* and, as has already been stated, is the only one known to occur in some countries where mildew is found. When the perfect stage occurs its presence is demonstrated by the production of small black sphaerical spore containing bodies (perithecia) upon the surface of infected plant parts. The perithecia are visible to the naked eye and when examined microscopically are found to contain colourless vesicles or sacs (asci) each of which in turn contains eight spores (ascospores). When this stage of the fungus occurs it can readily be distinguished from the pycnidia of the foot rot fungus *Phoma* (q.v.) by the superficial production of the perithecia upon the mildewed surfaces of the plant, by the presence of asci and by the absence of any pore (ostiole) or opening through which the spores are extruded.

The mildew producing fungi normally survive the winter by means of the perithecia which remain dormant until the following spring or by fungal threads which rest in the winter buds of attacked perennial plants. In the case of flax little is known of how the fungus survives from one year to another in those countries where perithecia are not known to occur. It may be that it is harboured by volunteer flax plants growing and surviving the winter along hedgerows and in other waste places or it may be that this mildew attacks some other plant and thus survives the winter on another host.

Powdery mildew of flax is not of great importance in the British Isles and has never been found affecting more than a few plants here and there in a crop. Even then, little serious damage appears to be done to the plant unless the attack occurs early in the development of the crop and thereby weakens the plant so as to prevent its proper growth. It may, however, cripple the growth of plants being grown under glasshouse conditions for experimental purposes.

Prevention and Control

So far it has not been necessary to prescribe measures for the control of this disease but its control should be achieved by dusting the crop with finely ground sulphur or spraying the plant with a sulphur containing fungicide (i.e. lime sulphur). Such a measure should be quite suitable for application under glasshouse conditions. Mildew is more apt to attack plants where the growth is rank and succulent and is therefore more likely to occur in crops grown in rich soil with too great a proporton of readily available nitrogen.

REFERENCES

Allison, C. C. (1934). Powdery mildew of flax in Minnesota. Phytopathology, 24, 305-7.

Colhoun, J. & Muskett, A. E. (1941). Powdery mildew, hail damage and heat canker of flax. Gdnrs' Chron. Ser. 3, 110, 30.

Homma, Y. (1928). On the powdery mildew of flax. Bot. Mag. (Tokyo), 42, 331-4.

Salmon, E. S. & Ware, W. M. (1927). The powdery mildew of flax. Gdnrs' Chron. 82, 34-35.

Škorić, V. (1926). Erysiphaceae Croatiae. Prilog fitopatološkosistematskoj monografyü našin pepelnica. Annales pro Experimentis Foresticis, Zagreb, 1, 52-118. (Abs. in Rev. appl. Mycol. 6, 124-125).

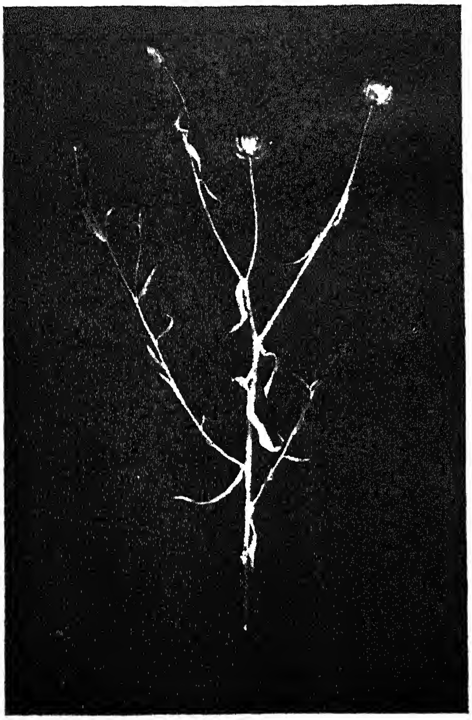


FIG. 45—Flax plant attacked by powdery mildew.

FIG. 46—Enlarged portion of the plant illustrated in Fig. 45 showing the typical white mealy appearance of the attacked organs.

SCLEROTINIA DISEASE

(*Sclerotinia sclerotiorum* (Lib.) Massee.)

General

The Sclerotinia disease of flax has been reported as occurring in Ireland, the U.S.A., and the U.S.S.R.

The fungus usually attacks the stems of the plants at about soil level or somewhat higher, the affected parts being killed very rapidly and soon becoming completely decayed. This results in the crop becoming lodged. On the surfaces and in the pith cavities of the dead straws the parasite produces fluffy white compact growths. These later become firm and form sclerotia which are firm and hard, and black on the outside. They can be distinguished from the sclerotia formed by the grey mould fungus (*Botrytis* q.v.) by their more or less sphaerical shape and their usually greater size ; the sclerotia of *Botrytis* are normally smaller, much flatter in shape and closely adpressed to the straw. Capable of withstanding adverse weather conditions the sclerotia, when deeply buried, may remain alive in the soil for long periods (probably many seasons) before showing any signs of growth. When but shallowly buried they germinate under the requisite conditions of temperature and moisture. On germination, small stalked, trumpet shaped cinnamon-brown bodies (apothecia) are produced. The inner surface of each trumpet shaped apothecium is lined with a spore bearing layer, the spores being contained in cylindrical sacs (asci). Each sac contains 8 ellipsoidal spores (ascospores) which are expelled forcibly into the surrounding air when ripe and the weather conditions are suitable for spore discharge. This discharge takes place during the summer and if there are flax plants in the neighbourhood, the spores may alight on them and germinate to produce infection. The fungus is world wide in distribution and is capable of attacking a very wide range of cultivated plants including the potato.

Prevention and Control

Fortunately, Sclerotinia disease is not common and is most apt to occur where flax is grown under wet conditions with a heavy undergrowth which encourages dampness around the bases of the stems. Care should therefore be taken to avoid these conditions in districts where the disease is known to occur. Land rich in nitrogen and liable to produce weak succulent plants should be avoided for flax. Since the parasite is soil borne control measures should also be based on long crop rotations and the detritus from diseased crops should not be allowed to reach fresh land. Flax should not follow a potato crop known to have been attacked by the disease and as the fungus may pass to flax plants from the stems of weeds, the importance of clean cultivation and the keeping of the crop as free as possible from weed growth is stressed.

REFERENCES

Vannah, H. P., Ray, C., & Wolf, F. A. (1944). Sclerotial disease of flax caused primarily by *Sclerotinia sclerotiorum* (Lib.) Massee. J. Elisha Mitchell Sci. Soc. 60, 99-108.

Parievskaya, A. P. (1931). Wet or white rot of flax caused by the fungus *Sclerotinia libertiana*, Fuckel. Materials for Mycol. and Phytopath. Leningrad 8, 165-170.

Pethybridge, G. H., Lafferty, H. A. & Rhynehart, J. G. (1921). Investigations on flax diseases. J. Dep. Agric. Ire. 21, 167-187.

RHIZOCTONIA DISEASE

(*Corticium Solani* (Prill. & Delacr.) Bourd. & Galz.). (*Rhizoctonia Solani* Kühn)

General

This disease has been reported from Canada, Kenya and the U.S.A., where it may cause considerable crop damage. When occurring in epidemic form the number of plants may be greatly reduced owing to seedlings being killed before their emergence through the soil. The first symptoms noticed on individual plants after emergence take the form of small brown lesions on the roots just below the soil surface. These lesions spread downwards on the roots as well as upwards towards the cotyledons and in the later stages of attack the affected portion of the stem is reduced to a dry pulp which may break or split to give a ragged appearance. Many of the plants wither and die prematurely taking on the general appearance of those affected with wilt (q.v.) while those which survive are usually stunted. Plants affected with *Rhizoctonia* can be readily distinguished from those killed by wilt (*Fusarium Lini*) by the absence of the characteristic spore pustules with sickle shaped spores which are so characteristic of the latter fungus.

The disease frequently makes its appearance in limited areas in the field and these may vary in size from a few feet across to more than an acre in extent ; in these areas practically every plant may be infected.

Prevention and Control

As the fungus responsible for the disease is soil borne little can be done to effect control other than to avoid planting in contaminated land and to adopt a suitably wide crop rotation.

REFERENCES

Tervet, I. W. (1937). An experimental study of some fungi injurious to seedling flax. Phytopathology, 27, 531-546.

Brentzel, W. E. (1923). Disease of flax caused by a species of *Rhizoctonia*. Phytopathology 13, 53.

Vanterpool, T. C. (1935) Seedling damage of flax caused by *Rhizoctonia solani* and *Pythium debaryanum*. Proc. World's Grain Exhib. Conf. Regina, 2, 300-2.

DAMPING OFF

(*Pythium* Spp.)

General

The attack of flax seedlings by species of the fungus *Pythium* to cause their damping off has been reported from Australia, Canada and the U.S.A. This disease is quite distinct from Scorch (q.v.) which is caused by *Pythium megalacanthum.*

When attacked, the cotyledons, young stems and roots of the seedlings develop reddish-tan coloured areas or the seedlings may be attacked and killed before their emergence through the soil. The lesions on the young root may vary from a small spot on one side, which has little apparent effect on the growth of the plant, to large areas which may encircle and involve the whole of the root tip with the result that a stunting of the plant occurs. Secondary roots may be produced above the rotted portion and by means of these the plant may be able to absorb sufficient water and nutrients to survive.

The species of *Pythium* responsible for the disease are soil inhabiting fungi and a microscopic examination of the diseased roots and cotyledons reveals the presence of the typical sphaerical reproductive bodies (oospores) of the fungus.

Prevention and Control

Damping off is favoured by any factor which delays the normal germination of the seed and the emergence of the seedlings. Such factors may be very cold weather, deep sowing, excessive soil moisture, soil acidity or the formation of a hard crust on the surface of the seed bed. Although the causal fungus is not seed-borne, seed disinfection with an effective fungicide usually brings about a decrease in the incidence of the pre-emergence phase of the disease. This is probably due to the disinfectant protecting cracked and damaged seed and thereby preventing its attack by soil fungi. In some cases applications of lime to the soil have been effective in reducing the damage.

REFERENCES

Millikan, C. R. (1945). " Damping off " disease of flax. J. Agric. Victoria, April, 1945, 177-181.

Vanterpool, T. C. (1935). Seedling disease of flax caused by *Rhizoctonia solani* and *Pythium debaryanum.* Proc. World's Grain Exhib. Conf. Regina 2, 300-302.

SCORCH

(*Pythium megalacanthum* de Bary)

General

This disease may be serious in Holland where it appears in late spring or early summer and affects the crop in patches. The centre of an affected patch is usually occupied by stunted plants where the leaves are brown and shrivelled to a distance of about half way up the stalk. The leaves above this point are yellow with brown and dried up tips, those higher up are yellow at the tip and limp while those at the top are green and turgid. By the shortening of the internodes of the stems the leaves grow close together in diseased plants. Towards the edge of the patch the symptoms become progressively less noticeable. Ultimately the very stunted plants die but those less severely affected may recover under favourable growth conditions. The affected patches may spread rapidly and cases are recorded where apparently vigorous crops have been destroyed within five days of the attack having been noticed.

The disease is reported as being caused by an attack of the root system by a soil inhabiting fungus *Pythium megalacanthum.* An examination of the root system of an infected plant shows broken areas through which the central cylinder or core of the root may be seen. The typical sphaerical sexual reproductive bodies (oospores) which possess echinulate or spiny walls are usually present in the cells of the roots.

Prevention and Control

It is regarded that cold damp spring weather favours infection and late sowing is said to reduce the incidence of the disease. The use of fertilizers which tend to produce an alkaline reaction in the soil is liable to increase the severity of an attack. The fungus appears to be capable of remaining in a viable condition in the soil for long periods since the disease has been observed in fields where flax had not been grown for twenty years.

REFERENCES

Diddens, H. A. (1931). Onderzoekingen over den Vlasbrand, veroorzaakt door *Pythium megalacanthum* **de Bary. Thesis Univ. of Amsterdam. 127 pp.**

van der Meer, J. H. H. (1928). Vlasbrand (brûlure du Lin). Tijdschr. over Planten-ziekten, 34, 126-146. (Abs. in Rev. appl. Mycol. 7, 578-9).

ROOT ROT

(*Thielaviopsis basicola* (Berk. & Br.) Ferraris)

General

This disease is known to occur in Germany, Holland, Ireland, the U.S.A. and the U.S.S.R.

In affected crops localised areas occur in which many of the plants may be dead while others are of a pale green colour and stunted in appearance. The aerial portions of the plants are free from disease and their death or stunted appearance is due to malnutrition resulting from the diseased condition of the roots which are often dead and black in colour. In other cases only portions of the roots, particularly the youngest, are affected and the remainder, being healthy, are able to maintain the life of the dwarfed plants.

Microscopical examination of the diseased roots shows the presence on them of fungus threads bearing thin walled spores (conidia) and thick walled dark coloured spores (chlamydospores). The conidia are short cylindrical colourless cells formed within the tips of the fungus threads. When the tip of the thread is ruptured the spores are pushed out so that the thread itself assumes the role of a case for the spores (Fig. 47). The chlamydospores are thick walled, more or less cylindrical, dark brown in colour and are formed in chains (Fig. 48). They are much larger and more robust than the conidia. At maturity the spore chains, which are frequently short, break up and each unit becomes a chlamydospore capable of surviving under adverse growth conditions.

Prevention and Control

Since *Thielaviopsis basicola* is capable of attacking the roots of a number of weeds such as groundsel (*Senecio vulgaris*) and goosefoot (*Chenopodium album*), the eradication of such weeds is of primary importance in formulating control measures. The parasite is soil borne but although the chlamydospores may remain viable in the soil for a considerable time, it is believed that the adoption of a suitably wide crop rotation will do much to check outbreaks of the disease.

REFERENCES

Kletschetoff, A. N. (1926). Injury to flax caused by *Thielavia basicola* Zopf. when the crop is grown uninterruptedly in the same soil. J. Sci. Agron. 12, 823-4.

Lafferty, H. A., Rhynehart, J. G. & Pethybridge, G. H. (1922). Investigations on flax diseases. J. Dep. Agric. Ire. 22, 103-120.

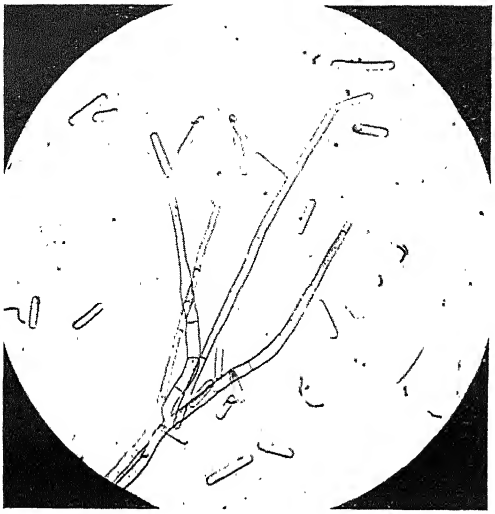


FIG. 47—Typical conidiophores of *Thielaviopsis basicola* showing the conidia being formed within them and extruded from their tips (x 300). The actual spore size ranges from 10-20μ x 4-5μ.

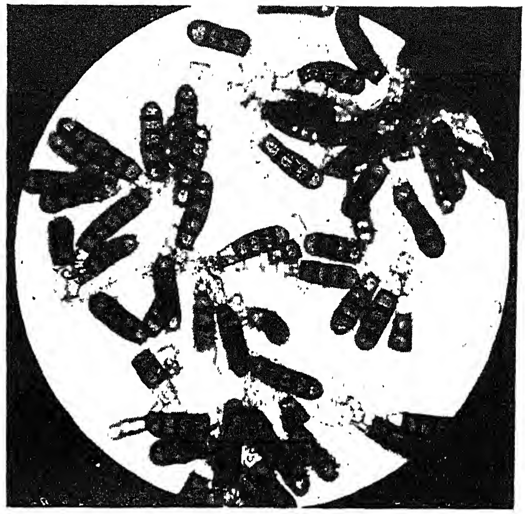


FIG. 48—The thick walled resting or chlamydospores of *Thielaviopsis basicola.* They are dark in colour and are produced in short chains, the individual spores separating at maturity. (x 300). The actual spore size ranges from 12μ x 5-8μ.

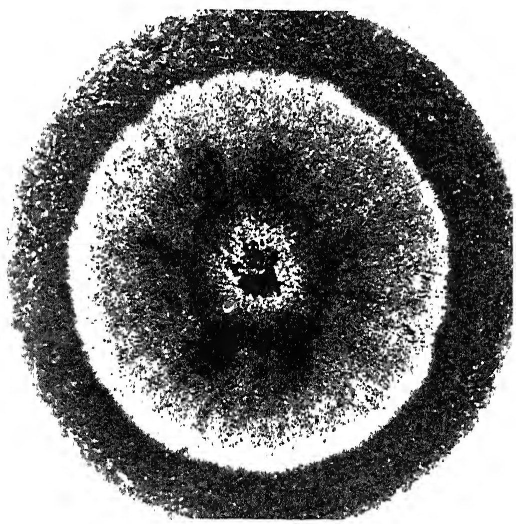


FIG. 49. Typical colony of *Thielaviopsis basicola* growing on 2 per cent. malt agar.

DISEASES CAUSED BY *ALTERNARIA* SPP.

(*Alternaria linicola* Groves & Skolko). (*Alternaria Lini* Dey)

General

The disease caused by *Alternaria linicola* is known to occur in the British Isles, Canada and Denmark while that caused by *A. Lini* has been recorded in India. In addition, diseases caused by unnamed species of *Alternaria* have been reported from Germany, India, the U.S.A. and the U.S.S.R. (including Siberia).

A. linicola attacks the seedlings and may produce symptoms of damping off sometimes accompanied by the development of a moist brown rot (Fig. 50). It is probably not a vigorous parasite and appears to attack plants which have been debilitated through drought or some other factor. The fungus is seed-borne and is regarded as being capable of inhibiting to some degree the germination of the seed.

A. Lini attacks the flowers which are killed and from which the attack spreads to the stem. Leaves may also be attacked and killed and in this case also the fungus passes into and spreads in the stem. In severe attacks the whole plant may be killed when it assumes a greenish black colour due to the production of fungal threads (hyphae) intermingled with chains of spores (conidia) on its surface.

The spores produced by *Alternaria* are rather typical and as they are frequently produced on the diseased plants, they form a ready means for identifying the fungus (Fig. 51). Each is dark brown in colour and consists of many cells ; the basal portion is flask shaped and it narrows towards the tip or beak which is one celled and which may be long or short. In many species the spores are borne in chains, the beak of one spore being attached to the base of the next while in others, of which *A. linicola* is an example, the spores tend to be borne singly and not in chains (Fig. 52).

Prevention and Control

The diseases caused by species of *Alternaria* have not yet appeared to be of great economic significance and measures for their control have not been elaborated. At the same time, as the fungi responsible are seed-borne, it is extremely probable that seed treatments proved to be effective for the control of other seed-borne parasites will prove equally effective in this case. Evidence of this being so has already been obtained in laboratory experiments carried out in Northern Ireland.

REFERENCES

Dey, P. K. (1933). An *Alternaria* blight of the linseed plant. Indian J. agric. Sci. 3, 881-896.

Groves, J. W. & Skolko, A. J. (1944). Notes on seed borne fungi. II. *Alternaria*. Canad. J. Res. C., 22, 217-234.

Loughnane, J. B. (1946). A seedling disease of flax caused by *Macrosporium* sp. Nature, Lond. 157, 266.

Moore, W. C. (1946). New and interesting plant diseases. Trans. Brit. mycol. Soc. 29, 250-258.

Neergaard, P. (1945). Danish species of *Alternaria* and *Stemphylium.* Taxonomy, Parasitism, Economical Significance. (Einar Munksgaard, Copenhagen).

FIG. 50—Two flax seedlings showing natural infection of the cotyledons with *Alternaria linicola.*

FIG. 51—The typical beaked spores of *Alternaria linicola* as produced on the infected tissues (x 50).

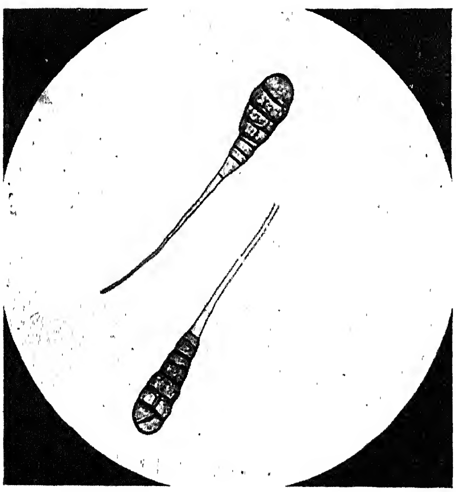


FIG. 52—Two spores of *Alternaria linicola.* The body of the spore is multicellular and dark in colour while the long tapering beak is typical of the species (x 300). The actual spore size (including the length of the beak) varies from 150-300 μx 17-24μ.

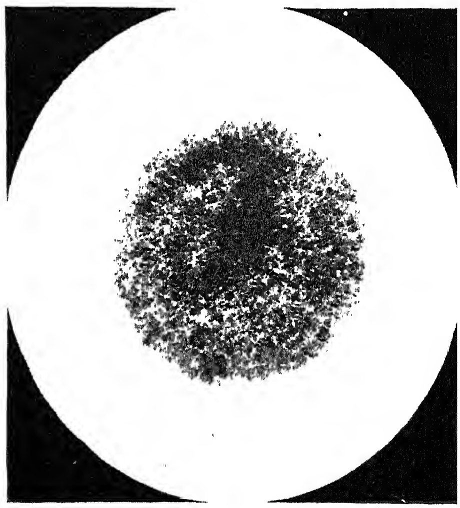


FIG. 53—A colony of *Alternaria linicola* growing on 2 per cent. malt agar.

DISEASES CAUSED BY *FUSARIUM* SPP.

(*Fusarium* spp.)

General

Apart from wilt caused by *Fusarium Lini* it has been found in Northern Ireland and the U.S.S.R. that other species of *Fusarium*, of which *Fusarium culmorum* (W.G.Sm.) Sacc. is probably one, sometimes infect flax straws following upon an attack of stem-break or the " firing " stage of rust.

A few weeks after an attack of stem-break has become well established in a crop, a rotting of the straw in the region of the stem-break lesion may be observed. This rot is caused by a species of *Fusarium* which enters the straw through the tissues already attacked and killed by the stem-break parasite. The portion of the straw affected by this secondary invader becomes light brown in colour and under moist conditions, whitish strands of the mycelium of the fungus appear on the surface. A reddish tinge is given to the centre of the affected area by the production of the pink to salmon coloured spore masses (sporodochia) of the fungus. The sporodochia contain large numbers of the typical sickle shaped spores produced by species of *Fusarium* which resemble those of *F. Lini* (q.v.).

Species of *Fusarium* may also attack flax straws already affected with rust. The fungus enters in the region of the black incrustations formed by the winter stage of rust (firing) and the first symptoms of the attack normally appear shortly before the crop is ready for pulling. The effect of the disease, which produces a rotting of the tissues, closely resembles that described in the case of stem-break (Fig. 54). The rot may extend to as much as half an inch (1.25 cm.) above and below the rust affected area. The production by the fungus of white fungal threads on the surface of the straw and of typical pinkish sporodochia may also be observed.

The effect of such an attack is to intensify the damage caused by stem-break and to extend that caused by rust. Apart from any adverse effect the disease may have upon the strength and quality of the fibre, in the case of attack following stem-break the plants commence to wilt and later die.

Prevention and Control

Little can be done to prevent damage caused by an attack of *Fusarium* following stem-break. The stem-break lesion is near the soil surface and if damp conditions prevail at the base of the crop, the secondary attack by *Fusarium* will be encouraged. Crops free from weeds are likely to be drier at the base. In the case of the disease following rust, the keeping of the straw under damp conditions after pulling would encourage it to spread even where it had not gained a foothold at the time of pulling, so that by taking care to keep rust affected crops as dry as possible the danger of *Fusarium* attack should be lessened.

REFERENCE

Kazina, O. (1935). The influence of the degree of flax seed infection by *Polyspora Lini* upon the crop damage and the yield. Plant Protection, Leningrad 6, 110-115.

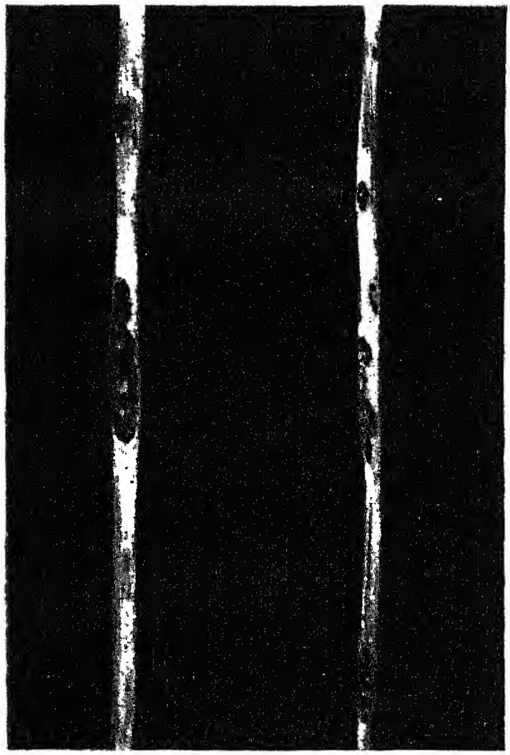


FIG. 54—Flax straws affected with rot caused by *Fusarium* sp. following upon the " firing " stage of rust.

DISEASE CAUSED BY *OLPIDIUM BRASSICAE* (WOR.) DANG.

General

Olpidium Brassicae is a microscopic fungus which has been recorded as occurring in connection with diseased flax in Belgium, Holland, Morocco and the U.S.S.R. It is usually found in plants which exhibit symptoms similar to those described under Scorch caused by *Pythium megalacanthum* with which fungus it is often associated. It is believed, however, that in some countries scorch may be caused by *Olpidium Brassicae* rather than by *P. megalacanthum*. When the roots of diseased seedlings are examined microscopically it is found that the rather spherical shaped resting sporangia of the fungus occur in the outer layers of cells. In these resting sporangia a number of spores (zoospores) are formed and these may be discharged through an exit tube which penetrates the wall of the host cell.

REFERENCE

Marchal, E. (1931). A propos de la " brûlure " du Lin. Pamphlet of Congrès National des Sciences (Belgium) (Abs. in Rev. appl. Mycol. 11, 182).

PASMO DISEASE

(*Sphaerella linorum* Wollenw.)

General

The disease of flax known as Pasmo or Spasm is caused by the fungus *Sphaerella linorum* Wollenw. and has been recorded as occurring in the Argentine, Canada, Denmark, Eire, Germany, Hungary, Kenya, New Zealand, Peru, Portugal, Rumania, Siberia, the U.S.A. and Yugoslavia. It has not been recorded in the United Kingdom but it is known that when flax plants are inoculated artificially with the responsible fungus under glasshouse or open air conditions, infection will result.

The earliest symptoms appear as small brown lesions on the cotyledons and leaves of young plants but, in the field, the disease is usually not noticed by the farmer until shortly before harvest when patches of the crop suddenly become brown and defoliation of the plants occurs. At this stage affected plants exhibit numerous brown lesions on the stems and leaves. On the stems the lesions frequently occur on the lower portions in the first place but later they extend upwards to the flowering branches and ultimately affect the seed bolls. In the early stages of attack on mature plants the lesions are small but they later expand, coalesce and encircle the stem, large portions of which may be involved in the attack (Fig. 55). The diseased parts of the stem often alternate with irregular bands of green uninfected portions giving the straw a characteristic mottled appearance. On the leaves the lesions are circular at first, greyish in colour but later they become brown.

In the case of both stems and leaves the diseased areas are dotted with minute dark coloured flask shaped spore containing bodies (pycnidia) which are more or less immersed in the superficial tissues of the plant

(Fig. 56). When a pycnidium is ripe the spores are extruded through the pore (ostiole) occurring at the tip of its short neck in the form of globular masses or as tendrils. The long thin needle shaped spores (Fig. 58) are very characteristic and at once serve to distinguish the fungus from *Phoma* which causes foot rot (q.v.). The stem and l af lesions in some cases are not unlike those produced by an attack of browning (*Polyspora Lini*) but as pycnidia are not produced by the latter fungus, the two diseases should not be confused.

Prevention and Control

In America it has been found that spores accumulate on the stems and, in the case of linseed, on the stubble which remains after the crop has been cut. Crop debris carrying the infection may, therefore, be a means of carrying the parasite over from year to year. This finding clearly indicates the importance of field sanitation and crop rotation as factors implicated in the control of the disease. Any crop debris known to be infected should be burnt and when linseed is grown the infected stubble should be burnt or ploughed in deeply. The chances of the fungus surviving from one crop to the next will be reduced if flax is not grown too frequently in the same land.

It has also been shown in America and in Eire that the responsible fungus may be seed-borne but apart from the finding that seed-borne infection may be controlled by hot water treatment of the seed no evidence is available to show if other methods of seed disinfection can be expected to give effective control of the disease.

Sphaerella linorum also attacks wild flax (*Linum angustifolium*) which in Ireland occurs to the south of the River Boyne. This indicates that if the viable parasite were imported through the medium of linseed or linseed cake it could become established on wild flax and thereby spread throughout a country after its introduction.

REFERENCES

Brentzel, W. E. (1926). The Pasmo disease of flax. J. agric. Res. 32, 25-37.

Colhoun, J. & Muskett, A. E. (1943). " Pasmo " disease of flax. Nature, Lond., 151, 223-4.

Garassini, L. A. (1935). El ' pasmo ' del Lino Phlyctaena? linicola Speg. Ensayo a campo de resistencia varietal y estudio morfológico y fisiológico del parásito. Rev. Fac. Agron. La Plata, 20, 170-261.

Krüger, E. (1941). The two most important parasites of flax—*Colletotrichum Lini* and *Septoria linicola* (*Sphaerella linorum*). Arb. biol. Abt. (Anst:-Reichsanst.) Berl. 23, 163-188.

Lafferty, H. A. & McKay, R. (1944). ' Pasmo ' disease on wild flax, *Linum angustifolium*. Nature, Lond., 154, 709.

Loughnane, J. B., McKay, R. & Lafferty, H. A. (1946). Observations on the Pasmo disease of flax and on the causal organism *Sphaerella linorum* Wollenweber. Sci. Proc. R. Dublin Soc. 24, 89-98.

Nattrass, R. M. (1943). The Pasmo disease of flax in Kenya, *Sphaerella linorum* Wollenweber. East African agric. J. 8, 223-6.

Newhook, F. J. (1942). Pasmo (*Sphaerella linorum*) on flax in New Zealand. N.Z.J. Sci. A. 24, 102-6.

Wollenweber, H. W. (1938). '*Sphaerella linicola*' n. sp. die Ursache der Amerikanischen Leinpest (Pasmo—oder 'Septoria'—Krankheit). Rev. Bot. Inst. 'Miguel Lillo,' 2, 483-494.

FIG. 55—Flax straws affected with Pasmo disease.

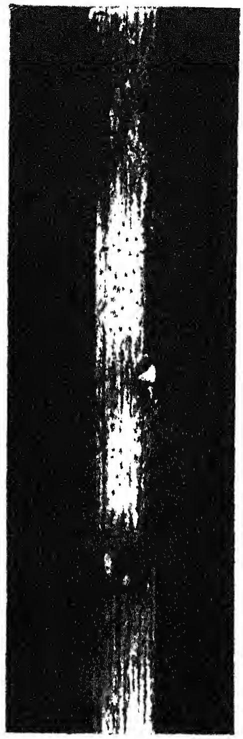


FIG. 56—Flax straw affected with Pasmo disease. It is enlarged to show the typical black pycnidia produced by the fungus (x 6).

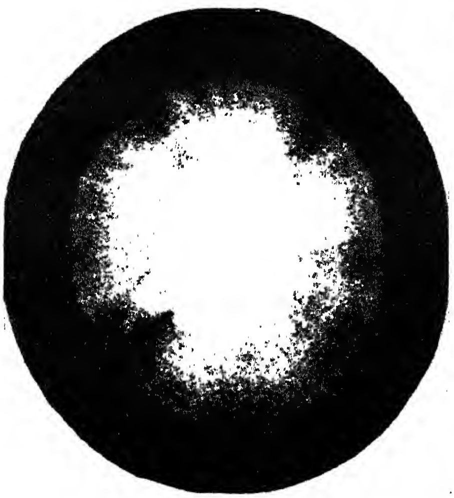


FIG. 57—Typical colony of *Sphaerella linorum* growing on 2 per cent. malt agar.

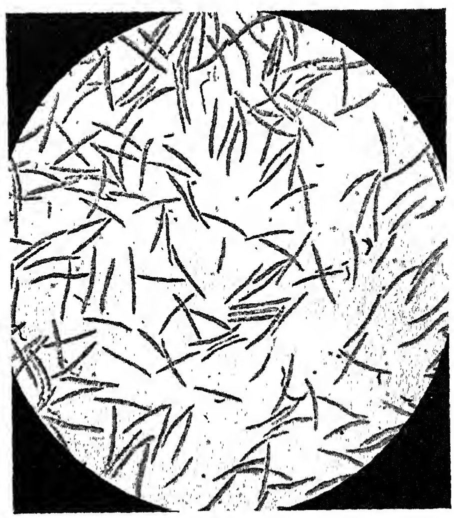


FIG. 58—Typical group of spores produced by *Sphaerella linorum* (x 300). The actual size of the spore ranges from 21-33μ x 2.5-3.3μ.

DISEASES CAUSED BY BACTERIA

General

The study of bacterial diseases of flax has up to the present been largely confined to the U.S.S.R. where it is believed that they may substantially reduce the yield of straw and seed. In the U.S.S.R. three groups of bacterial diseases of flax have been differentiated (1) those attacking the plant, (2) those reducing seed germination, and (3) those inducing physiological changes in the root system without visibly affecting the tissues.

Russian workers suggest that these diseases appear to be largely controlled by proper tillage on virgin soil and the use of suitable fertilisers.

REFERENCES

Beresova, E. & Savtchenkova, M. (1935). Bacterial diseases of flax. Microbiol. 4, 103-120.

Johnson, J. (1937). Relation of water-soaked tissues to infection by *Bacterium angulatum* and *Bact. tabacum* and other organisms. J. agric. Res. 55, 599-618.

Jaczewski, A. A. (1928). Concerning the diseases of oil seed plants. Reprinted from Oil and Fats producing Industry, 4., 1-11. (Abs. in Rev. appl. Mycol. 8, 381-2.)

VIRUS DISEASES

No virus disease of the flax crop was reported until recently when a malady attributed to the beet curly top virus was recorded as being widespread in areas of California during 1944. The symptoms of the disease include irregularity and waviness of the leaves which are closely grouped at the growing point, gradual chlorosis of the whole plant usually followed by death, marked reduction of the inflorescences, tortion and blistering of the petals accompanied by failure to expand, and a pronounced discolouration of the tap root and crown phloem. When plants of a height of from 8—10 in. are infected they often continue to grow and develop the characteristic foliar symptoms and show a coiling of the stem tip while the subsequent branches tend to be deflected from their normal positions thus producing a spreading rather than an erect growth habit of the plants. The virus is spread by the insect vector or carrier *Eutettix tenellus* and early sown crops (October-November) are the most severely damaged, those sown later probably owing their escape to the seasonal migration of the vector in the autumn. Infection is highest at the margins of fields and in places where the stand is sparse.

Flax appears to be susceptible to certain other virus diseases when infected experimentally but these have not been found to occur naturally in the crop.

REFERENCES

Barnett, H. L. & Houston, B. R. (1944). Curly top on flax and other flax diseases in central California in 1944. Plant Disease Reptr. 28, 507-8

Severin, H. H. P. & Houston, B. R. (1945). Curly top and California-Aster-yellows diseases of flax. Phytopathology, 35, 602-6.

BRAID VALLEY DISEASE

General

In 1944 a curious failure of the flax crop occurred in the Braid Valley district of Northern Ireland. The area involved was confined to two narrow belts running N. and E. of Ballymena, Co. Antrim, to a distance of some 10 miles. The heavier damage was caused in the eastern portion (the Braid Valley) where almost a thousand acres of crop were affected.

Where this disease occurs the crop brairds normally and the subsequent growth until early June is usually satisfactory. From then on, when the plants are from 6—9 in. in height, patches are observed where the plants have ceased growth. Within a short time the effect becomes most noticeable and the patches tend to increase in size. Ultimately the plants die and disappear so that by mid-July the crop may have become a complete failure where the attack is severe. The great variation in the extent of the damage occurring from field to field is a feature of this disease.

The symptoms shown by affected plants bear some resemblance to those of wilt (q.v.) but a close examination reveals distinct differences. The plants become generally unhealthy ; they exhibit distinct yellowing, especially in the lower portions, and growth ceases completely. The lower leaves fade and die while those around the growing point remain green and the plant takes on a tufted appearance owing to the crowding of the leaves at the apex due to the slowing down of growth. The stem also remains green and does not become discoloured as is so often the case with other diseases. When growth has ceased the plants dwindle in size and they finally collapse and disappear. Occasionally small lateral branches are produced from the axils of the cotyledons. No disease lesions of any kind are observed nor are any traces of damage apparent (Fig. 59).

In spite of the symptoms resembling those likely to result from a parasitic attack, particularly of the root system, no parasitic organism has so far been found to be associated with the disease and up to the present the cause remains undetermined. No evidence has been obtained to show that it is a deficiency disease resulting from an insufficient or unbalanced food supply nor can it be said that it occurs in a particular set of circumstances connected with the siting of the land or any given system of crop husbandry. All that is known is that it tends to occur in a severe form in the Braid Valley area and that the severity of the attack may vary considerably from season to season.

Some evidence has been obtained which suggests that certain varieties of fibre flax are more prone to attack than others and Figs. 60-63 show the effect of growing varieties of flax in soil taken from a field where the disease had occurred in epidemic form. Whereas the blue flowering varieties, Liral Prince and Stormont Gossamer, have succumbed the white flowering variety, Concurrent, has withstood the attack and is producing a normal crop. It may be significant that in the Braid Valley area, which is a good flax growing district where flax has been grown

successfully for many generations, it has been customary for farmers to grow a white blossom variety in preference to blue. This was not possible during the period of the 1939-45 war as only seed of blue blossom varieties was available.

Prevention and Control

Where this disease occurs the available evidence suggests that a white blossom flax should be grown in preference to blue. As the fibre value of blue flowering varieties is greater than that of white blossom great care should be taken to obtain a correct diagnosis so that the growing of flax of a somewhat inferior type will be avoided unless it is essential. As the intensity of the disease seems to vary greatly with seasonal conditions, too much reliance should not be placed upon the results obtained by the growing of any particular variety for only one season.

FIG. 59—Flax plants (Liral Prince) showing the typical symptoms of Braid Valley disease, including the formation of weak axillary shoots at the level of the cotyledons.

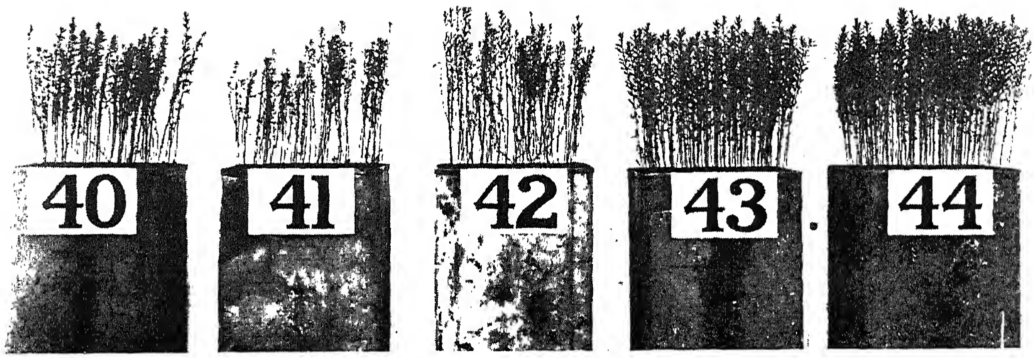


FIG. 60—Flax plants growing in soil prone to produce crops affected with Braid Valley disease (1944). 40, Stormont Gossamer ; 41-42, Liral Prince ; 43-44, Concurrent.

FIG. 61—Flax plants growing in soil prone to produce crops affected with Braid Valley disease (1944). 42, Liral Prince ; 43, Concurrent.

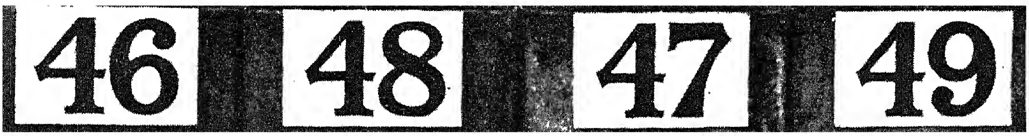


FIG. 62—Flax plants growing in soil prone to produce crops affected with Braid Valley disease (1946). 46-47, Liral Prince ; 48-49, Concurrent. Sown, 3rd April, 1946. Photographed, 14th June, 1946.

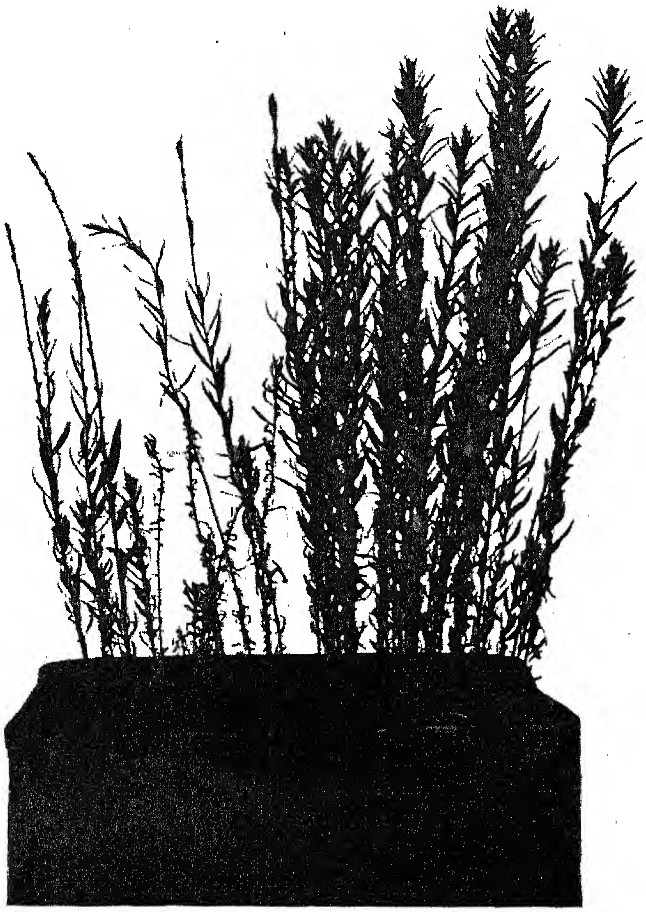


FIG. 63—Flax plants of the varieties Liral Prince and Concurrent growing in the same pot of soil (1946) taken from a field where Braid Valley disease had occurred in 1944.

DROOP

General

Droop has been recorded as occurring in Ireland but does not appear to have been noted elsewhere.

The first symptoms of the disease appear in early July when the plants in localised areas of the crop present a yellowish appearance as if prematurely ripe. On inspection the upper portions of the plants show signs of drooping but are free from the symptoms of wilt (Fig. 64). In the case of plants which have not commenced to branch at the apex as a preliminary to flowering, the earliest symptoms take the form of a yellowing of the tops, while where growth is more advanced and branching has already taken place the yellowing occurs on the foliage and stems immediately below the lowermost of the branches. After the onset of yellowing the droop becomes pronounced and the buds in the axils of the lower leaves which normally remain dormant, are stimulated into growth and develop into branches. Ultimately the affected portions of the main stems die but the secondary branches and the lower parts of the main stems remain normal.

Since the affected parts of the stems of drooping plants are of a soft herbaceous nature it would appear that droop is due to the non-development of the normal fibre elements in the stems. Microscopic examination of cross sections of the stems of affected plants show in fact that the loss of rigidity is due to the absence of the normal thickening in the walls of the fibre elements (Figs. 65-66). The suggestion has been put forward that in affected plants the normal thickening of the fibre elements does occur but that, for some unknown reason, it subsequently disappears.

No parasitic micro-organism has been found to be associated with diseased plants and no satisfactory explanation has so far been advanced to explain the cause of droop.

REFERENCE

Lafferty, H. A., Rhynehart, J. G. & Pethybridge, G. H. (1922). Investigations on flax diseases. J. Dep. Agric. Ire. 22, 103-120.

FIG. 64—Flax plants affected with droop.

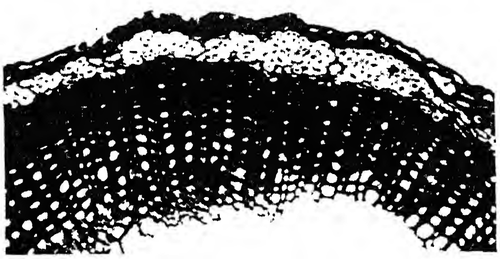


FIG. 65—Portion of a transverse section of a healthy flax straw showing the characteristic fibre bundles (light in colour) produced just below the epidermis or skin (x 65).

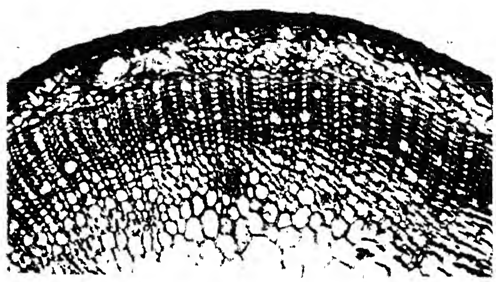


FIG. 66—Portion of a transverse section of a flax straw affected with droop. It will be seen that the fibre bundles are lacking and this results in a consequent lack of strength in the straw (x 65).

HEAT CANKER

General

Heat canker of flax has been reported from the British Isles, Canada and the U.S.A. while symptoms resembling this disorder have been recorded in Holland.

The disease is caused by the surface layer of the soil becoming overheated with the result that the stems of seedling plants are damaged in the early stages of their development. Plants up to 5 in. (12.5 cm.) in height may show the characteristic symptoms of heat canker. The outer tissues of the stem around ground level are killed and it consequently becomes very constricted in this region (Fig. 67). Frequently, affected plants fall over and die so that to some extent the symptoms may resemble those of damping off. In many cases a swelling of the stem above the constricted portion occurs and from the swollen region young roots are formed by the plant (Fig. 68). The development of these roots often enables the plant to survive for a time.

Flax seedlings which are grown under hot dry conditions are less susceptible to attack than more succulent plants which have been liberally supplied with moisture. Seedlings grown in a soil with a surface mulch overlying a firm seed bed are less likely to be affected with heat canker than those growing in soil with the surface layer compacted by rain or some other means, so that it is brought into close contact with the stems. In the latter case the surface layer of the soil becomes overheated when high temperatures prevail and acts as a conductor of heat to the stems of plants with which it is in close contact. In a temperate climate like that prevailing in Northern Ireland, damage is sometimes observed in the case of plants growing in fields where cultivation methods have allowed large air pockets to remain beneath the surface of the top soil (" bridged land "). The air pockets serve to insulate the top soil which becomes readily overheated at air temperatures which would not have the same effect in the case of more closely compacted land. Since dark coloured soils absorb more heat than those which are light in colour there is reason to believe that damage may be more severe in dark soils.

Prevention and Control

Heat canker may be reduced or prevented by ensuring that the soil conditions outlined above and under which it is prone to occur, are avoided, in so far as this is possible, by cultivation methods. Earlier sowing and the establishment of a reasonably thick braird will assist in the prevention of damage.

REFERENCES

Colhoun, J. & Muskett, A. E. (1941). Powdery mildew, hail damage and heat canker of flax. Gdns' Chron. Ser. 3. 110, 30.

McKay, R. (1940). Heat canker of flax. J. Dep. Agric. Éire, 37, 383-6.

Moore, W. C. (1943). Diseases of crop plants. A ten years' review (1933-1942). Minst. Agric. Lond., Bull. 126.

Reddy, C. S. & Brentzel, W. E. (1922). Investigations of heat canker of flax. U.S. Dept. Agric. Bull. 1120.

FIG. 67—Heat canker of young flax plants.*

FIG. 68—Heat canker of flax showing the formation of secondary roots.*

* Reproduced by kind permission of H.M. Stationery Office from photographs taken by Mr. W. F. Buck and published in the Ministry of Agriculture Bulletin No. 126.

HAIL DAMAGE

General

Damage to flax attributable to hail has been reported from the British Isles, Germany, New Zealand, Siberia, the U.S.A. and the U.S.S.R.

Light hail showers may have no effect upon the crop but heavy showers may cause considerable damage depending to some extent upon the age of the plants at the time of the storm. Very young seedlings may have the cotyledons completely broken off on account of their tenderness, and even the growing point of the plant may be cut off. The latter effect is the more serious since it promotes branching which results in a decrease in the crop value. In these islands the main damage caused by hail is due, not to the decapitation of seedlings, but to the development of swellings on the stems (Fig. 69). The swellings which usually appear about two weeks after the hail storm may be large, knotty, of an irregular shape and in most cases they are most prominent on that side of the stem bruised by the hail, although the whole circumference of the stem may be involved. Sometimes small dome shaped swellings covered by a smooth unbroken epidermis also develop on the stem but these rarely extend more than half the way round. The larger swellings constitute points of weakness at which the straws frequently break either before pulling time or during the processing of the crop. Individual stems are usually swollen at one point only and the height above ground of these points of injury is fairly uniform for any one crop due to the damage having been sustained by all the plants at the same time. It has been suggested that the proportion of the plants affected is greatest where the crop is thin.

REFERENCES

Baylis, G. T. S. (1939). Hail injury to flax. *Linum usitatissimum.* **N.Z.J. Sci. 21, 244A-248A.**

Colhoun, J. & Muskett, A. E. (1941). Powdery mildew, hail damage and heat canker of flax. Gdns' Chron. Ser. 3. 110, 30.

Schilling, E. (1938). Der Flachs als Faser—und Olpflanze. Tobler F. 275 pp. Berlin.

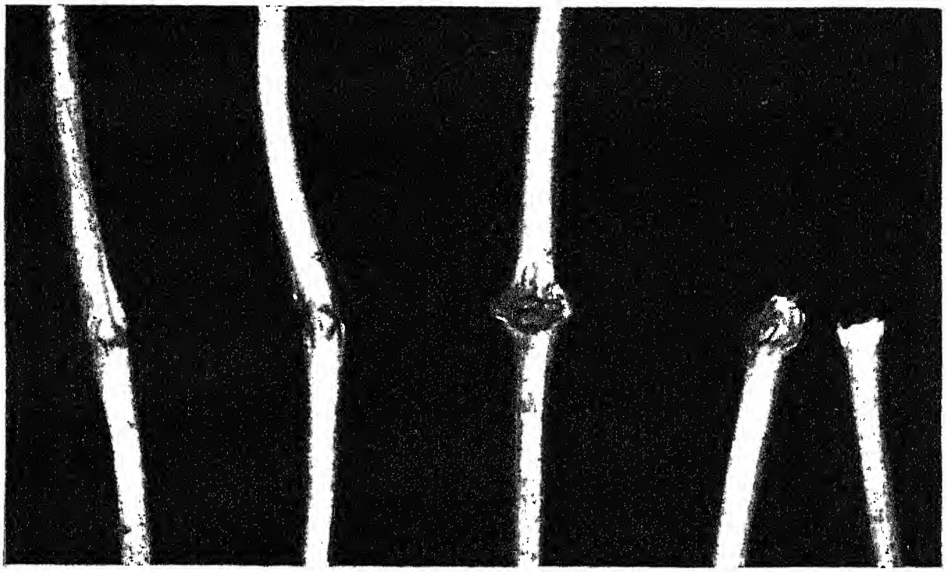


FIG. 69—Flax straws showing damage by hail. The specimen to the right has been broken to show the brittle nature of the straw at the point of injury.

FALSE BROWNING

General

This disease has been recorded in Australia and New Zealand where it is believed to be the result of an abortive infection with rust (*Melampsora Lini*) under conditions of high temperature.

The extent to which infection may occur varies considerably from small patches of a few square yards in area to cases where almost the entire crop may be involved. In the mass diseased plants appear brick red in colour. When an individual specimen is examined it is seen that the false browning lesions are normally confined to the upper half of the plant. On the straw the lesions are elongated in form and may be from a few millimetres upwards in length ; they exhibit a marked reddish brown discolouration. Usually individual lesions coalesce so that the whole of the upper portion of the straw becomes involved. On the leaves the lesions are darker and if a large area is affected the leaf becomes twisted and frequently falls from the plant. It is typical of the disease that the lesions always occur around abortive rust pustules which are white in colour due to the complete absence of the summer spores (uredospores) of rust. Development of the rust pustules ceases completely and the winter spores (teleutospores) are not formed later.

False browning has been noted to appear in Australia about a week after sudden hot spells during which temperatures of 80°F. (27°C.) or higher were recorded. It has been proved experimentally that lesions typical of those occurring naturally are produced around rust pustules on the stems and leaves of flax plants subjected to a constant temperature of 98°F. (37°C.) and a relative humidity of 85 per cent. for periods ranging from 6-30 hours. The symptoms were well developed approximately three days after such heat treatment and the most vigorous reactions occurred around very immature summer spore (uredospore) pustules subjected to the longest exposures to heat treatment. Heat treatment of winter spore (teleutospore) pustules resulted in little false browning.

REFERENCE

Millikan, C. R. (1945). A " False " browning reaction to rust (*Melampsora Lini*) infection in flax. J. Agric. Victoria, Feb., 1945, 83-92.

BRONZING

General

In certain years a condition which superficially resembles browning caused by *Polyspora Lini* has been observed in flax crops in Northern Ireland. The symptoms of this disease usually occur in the marginal areas of crops or in crops grown on shallow soils. When affected plants are viewed in the mass the impression of a crop infected with browning is gained but when an individual specimen is examined it is seen that although the stems at the top of the plant show typical brownish discolouration,

no disease lesions similar to those resulting from attack by *Polyspora Lini* are observed.

So far, it has not been possible to isolate any parasitic organism from affected plants and it is believed that the condition results directly from physiological causes.

A somewhat similar condition to bronzing has been reported from Australia but in this case the symptoms have been shown experimentally to occur after the waterlogging of the soil. It is not possible to say whether or not the Australian disease is the same as that occurring in Northern Ireland.

FLAX DODDER

(*Cuscuta Epilinum* Weihe)

General

Flax dodder, which is a parasitic flowering plant, appears to have been recorded in practically every flax growing country although in many cases it is but of minor importance. It possesses no leaves, is yellow to yellowish-red in colour and belongs to a very small group of flowering plants which are entirely dependent for their food upon the plants serving as their hosts.

The dodder seed which is light brown in colour and not unlike a clover seed in size and appearance, germinates to produce a small seedling with a yellow thread-like tip. This tip executes a typical revolving movement until it makes contact with a flax plant to which it attaches itself by coiling around the stem (Fig. 70). Where it touches the stem it produces sucker like organs (haustoria) which penetrate the tissues of the flax stem from which they extract the food necessary for the nourishment of the parasite. The root of the dodder seedling then dies and the plant becomes entirely dependent upon the flax for its food supply. From now on it makes rapid growth (Fig. 71) and a considerable portion of the crop may soon become involved in the attack. In or about July clusters of yellowish green flowers are produced along the yellowish-red twining and coiling stems (Fig. 72). Each fertilised flower eventually produces a capsule which may contain up to four seeds.

Prevention and Control

The first essential in preventing an outbreak of dodder in a flax crop is to ensure the use of seed entirely free from the seeds of dodder. As these seeds are so different in size and shape from those of flax, the thorough cleaning of flax seed does not present a difficult problem when up-to-date seed cleaning machinery is available but where this is not the case, the purity of the seed sample should receive special attention. If dodder exists in a crop care should be taken to prevent its spread to neighbouring crops through the transfer of small pieces of dodder stems to the clean crop. Such stem portions are capable of coiling around flax stems, developing haustoria, and thereby infecting the crop.

When a patch of dodder is observed in a flax crop the whole of the crop in the affected area should be pulled and burned immediately. Pulling should be commenced from a safe margin on the outside of the area and should finish at the centre of the infection. Care should be taken not to transport seeds or shoots of the parasite to clean areas in the crop. Where a general crop infestation occurs the seed, if harvested, should be finely ground and used for feeding purposes. Where flax or clover or any other crop has been attacked by dodder, the crop should not be grown again for a period of five years in the land where the infestation occurred. During this period tillage should be shallow so that the dodder seeds are not buried deeply.

Outbreaks of flax dodder have occurred in Northern Ireland from time to time but the infestation has never become general. They have nearly always been observed in crops grown from seed imported from countries where the parasite commonly occurs and immediate steps have been taken to deal with the parasite as soon as it was observed.

REFERENCE

Pethybridge, G. H. & Lafferty, H. A. (1920). Investigations on flax diseases. J. Dep. Agric. Ire. 20, 325-342.

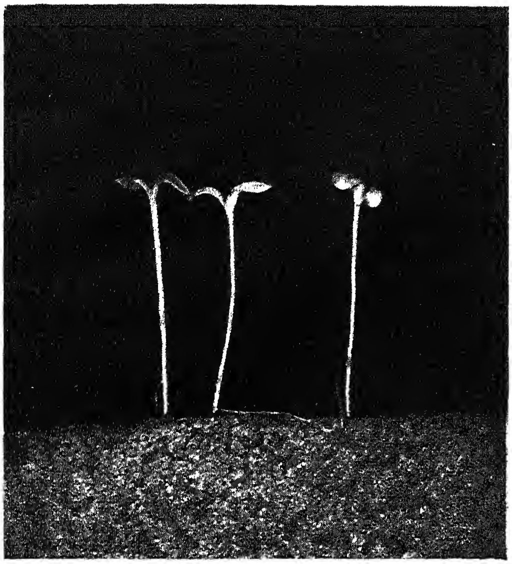


FIG. 70—The early stages of a dodder (*Cuscuta Epilinum*) attack on flax. The dodder seeds have germinated in close proximity to the flax seedlings and the tips of the shoots are commencing to coil around the stems of the seedlings.

FIG. 71—An intermediate stage of dodder attack. Nourished by food extracted by the suckers or haustoria from the young flax plant, the dodder shoots are growing rapidly and are ready to attack other flax plants in the vicinity.

FIG. 72—An advanced stage of dodder attack. The dodder plant has now grown to maturity at the expense of its host and is producing its flower clusters which are bunched along the stem. A typical flower cluster is shown in the illustration.

Potassium deficiency

Experimental work in Great Britain has shown that flax plants grown in a potassium deficient medium exhibit stunting of the shoots with the internodes shorter than normal while the leaves develop a brown scorch at their tips and wither. The first effects on the leaves become apparent at the bases of the shoots. In Germany it has been suggested that flax plants receiving an inadequate potash supply develop dark coloured foliage with a browning of the tips of the leaves.

A fairly definite type of yellowing of flax seedlings has been noted in Irish crops within a few weeks after sowing. The trouble shows itself as a paleness or chlorotic condition of the foliage of the seedlings although the cotyledons may be of the normal green. Affected plants do not die prematurely but remain stunted in growth and produce a very inferior crop. Since this condition does not usually make its appearance in crops to which a potassic fertilizer has been applied, and since when 1-2 cwt. of sulphate or muriate of potash per acre is applied to an affected crop the plants show complete recovery, it is assumed that these symptoms are the result of a deficiency of potassium. This conclusion is, however, not altogether supported by experimental studies of the physiology of the plant.

Nitrogen deficiency

It has been demonstrated that when flax plants are not supplied with adequate supplies of nitrogen little growth is made so that the shoots are dwarfed, thin and very upright in habit bearing but few floral branches. The leaves are small, erect, pale green or yellowish green with early defoliation occurring and progressing from the bases of the shoots. Ripening in such cases occurs early and few flowers or fruits are produced.

Normally, flax in the field does not exhibit pronounced symptoms of nitrogen starvation and the condition has but rarely been observed in Northern Ireland crops.

Calcium deficiency (Withertop)

This disease has been studied in detail in Australia but it is also believed to occur in the British Isles.

Flax plants subjected to a mild attack of withertop make good growth until they are a foot or more in height. Symptoms then appear rapidly, the first sign being the occurrence of a sharp bend approximately 2-4 in. (5-10 cm.) below the tip of the plant. At this point the stem loses rigidity and falls down so that it hangs in a vertical position. When bending first occurs there is no sign of browning at or above the bend but necrosis soon sets in at this point and extends rapidly until the whole of the bent over portion is dead. The stem below the bend appears to remain normal. These are the symptoms usually noted but the disease

may not appear until some time after flower bud formation when individual flower stalks only may collapse. Affected plants may occur in well defined patches or the disease may be distributed more or less uniformly throughout the crop.. It is believed that withertop is associated with a waterlogged condition of the soil especially where the soil is acid in reaction and contains a high percentage of clay.

When flax is grown under conditions of acute calcium deficiency the plants usually do not survive the seedling stage. In such cases the bottom leaves become abnormally dark green while the tops of the plants become chlorotic, this condition being followed rapidly by a necrosis of the upper leaves from the tips while the lower leaves remain apparently normal. Finally the whole plant dies. This severe form of the disease does not usually occur under field conditions.

Withertop can be controlled by the application of slaked lime or ground limestone before sowing. As little as 3 cwt. of slaked lime per acre has been found to effect an appreciable reduction in its incidence and 4 tons of ground limestone has been found to prevent its occurrence.

Zinc deficiency

A disease shown to be due to a deficiency of zinc has been recorded in Australia. Plants subjected to such a deficiency are stunted. Greyish brown collapsed spots appear on the younger leaves where they are most marked on the upper surfaces; on the under surfaces they appear as dark green blotches. When dry these lesions become light brown to white in colour while bronze spots are developed on later formed leaves. The internodes between leaves are short giving a rosette appearance to the top of the plant. Later the top of the main stem becomes necrotic and all the lower leaves die from the tip downwards although the stem itself may remain green for some time afterwards. Secondary shoots may be produced from the bases of affected plants and on the leaves of such shoots bronze coloured spots also develop followed by necrosis of the leaves from the tips. Finally, if the deficiency is very acute, the whole plant dies.

The disease may be prevented by the application of agricultural zinc sulphate at the rate of about 20 lb. per acre. In Australia 1 cwt. of superphosphate per acre is usually applied with the zinc sulphate.

Iron deficiency

A disease due to a deficiency of iron has been observed in Australia and Germany. Characteristic symptoms appear about three weeks after germination, the new leaves produced at this time being yellow to white in colour and devoid of any green pigment. Subsequent growth is very retarded and, due to the shortening of the internodes, the top of the plant assumes a rosette appearance. Many of the affected plants die but under warm dry weather conditions some may recover and after a time begin to produce normally coloured leaves. The disease is usually most severe in wet cold soils and in those containing a high percentage of limestone.

When seedlings are sprayed with a 1 per cent. solution of ferrous sulphate as soon as the symptoms appear, the normal green colour develops in the leaves within a few days and the plants recover.

Phosphorus deficiency

Symptoms of phosphorus deficiency in flax crops have been observed in Australia. The affected plants were stunted and darker green in colour than normal while the leaves remained small and were closely pressed against the stem. The lower leaves on such plants died prematurely.

Magnesium deficiency

Flax plants subject to a deficiency of magnesium show a stunting of growth and a slight general chlorosis. The lower leaves of affected plants die much earlier than normal, death occurring characteristically from the tips.

Copper deficiency

The symptoms associated with copper deficiency in flax are stunting and general chlorosis of the plants while the leaves, particularly those on the upper part of the plant, show marked inrolling and twisting.

REFERENCES

Adams, D. B. & Piper, C. S. (1944). The use of zinc for flax. J. Dep. Agric. S. Aust. 47, 422-426.

Flor, H. H. (1943). Chlorotic dieback of flax grown on calcareous soils. J. Amer. Soc. Agron. 35, 259-270.

Millikan, C. R. (1942). Symptoms of zinc deficiency in wheat and flax. J. Aust. Inst. agric. Sci. 8, 33-35.

Millikan, C. R. (1944). " Withertop " (Calcium Deficiency) disease in flax. Dep. Agric. Victoria, Biological Branch Tech. Bull. No. 2.

Millikan, C. R. (1945). Iron deficiency chlorosis of flax. J. Dep. Agric. Vict. 43, 133-134.

Pethybridge, G. H., Lafferty, H. A. & Rhynehart, J. G. (1921). Investigations on flax diseases. J. Dep. Agric. Ire. 21, 167-187.

Scholz, W. (1934). Uber die chlorose des Leins in ihrer Beziehung zum Eisen und Mangan. Zeitschr. Pflanzenernähr., Düng. u. Bodenk. 34, 296-311. (Abs. in Exp. Station Rec. 75, 362.)

Wallace, T. (1944). The Diagnosis of Mineral Deficiencies in Plants. Supplement. H.M.S.O.

APPENDIX I

The Seed-Borne Parasites of Flax and their Detection by the Ulster Method of Seed Examination

The parasites responsible for some of the most serious diseases of flax including seedling blight, stem-break and browning, foot rot, grey mould and wilt, may be carried by the seed and as contaminated seed samples cannot be diagnosed satisfactorily by eye inspection, some other method of examination is necessary. The Ulster method was devised in 1939 for this specific purpose. It is simple and consists of plating out the seeds on a layer of two per cent. malt extract agar poured into Petri dishes prepared and sterilized as for mycological culture work. A convenient size of dish for use measures 9.0 cm. in diameter and ten seeds are plated in each dish. To encourage growth of the fungi the dishes are incubated at 22°C. and are ready for examination after five days. This means that a satisfactory test made to determine the extent to which a sample of flax seed is contaminated with seed-borne fungal parasites may be carried out at any time of the year in a period of five days. Using a representative and well mixed sample of seed a result of qualitative significance can be obtained by the examination of 100 seeds but if a reliable quantitative result is required, 500 seeds must be examined. Apart from the growth of parasitic organisms, other comparatively harmless fungi and bacteria will grow out from seeds which they may contaminate, but it has been found that their occurrence does not readily interfere with the recognition of the parasites for the observation of which the method is primarily intended. The growths can be recognised by eye inspection and a trained observer can work rapidly and accurately after a little experience. The following illustrations (Figs. 73-87) indicate how the method works in practice.

The Ulster method has been employed annually over a three year period for the examination of 3000-4000 samples of flax seed produced in the United Kingdom and the results of this survey when analysed and made available will throw considerable light upon the distribution of seed-borne parasites as they occur in seed produced in Great Britain and Northern Ireland.

REFERENCE

Muskett, A. E., and Malone, J. P. (1941). The Ulster method for the examination of flax seed for the presence of seed-borne parasites. Ann. appl. Biol. 28, 8-13.

In the following illustrations an attempt is made to picture the growth forms of some of the fungal parasites and moulds as they occur when flax seed is examined for their presence by the Ulster method. The series of illustrations to the left denoted by even numbers show the fungal colonies as viewed from the top side of the Petri dish while those to the right denoted by odd numbers show their appearance when viewed from the underside of the dish.

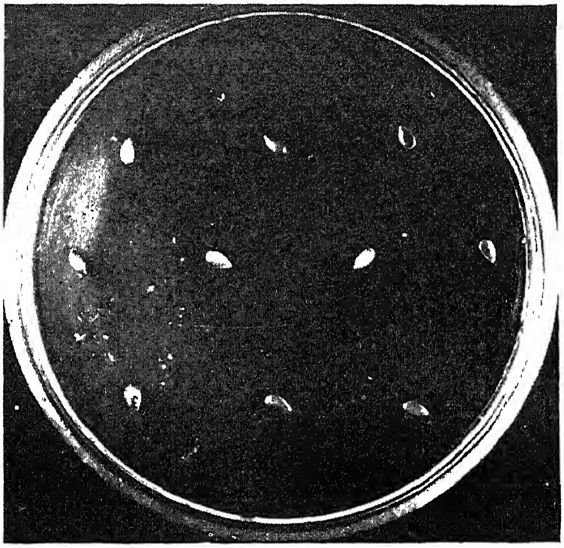


FIG. 73—A Petri dish filled with nutrient agar and containing 10 flax seeds spaced equidistantly on the surface of the medium. The dish is in readiness for carrying out the test.

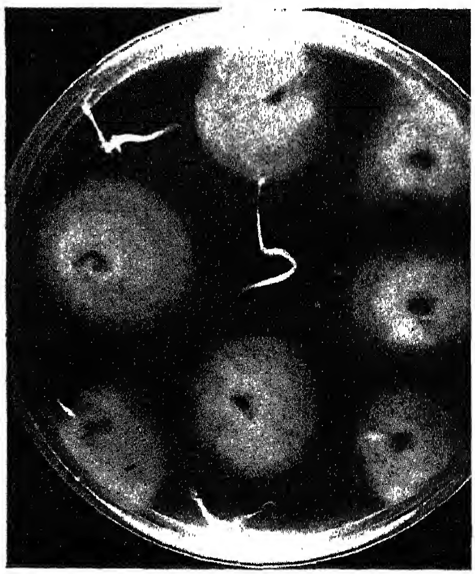


FIG. 74 Fig. 75

Colletotrichum linicola (Seedling Blight).

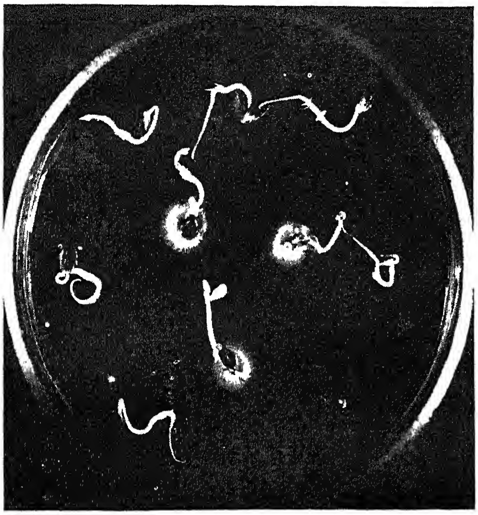


FIG. 76

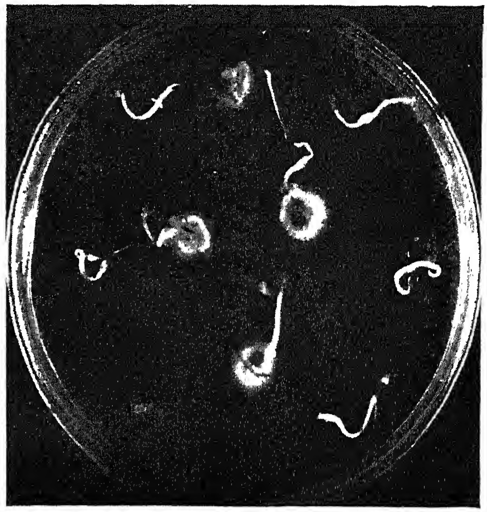


FIG. 77

Polyspora Lini (Stem-break and Browning)

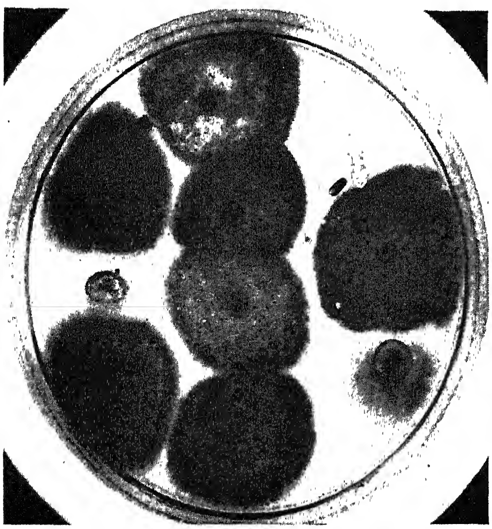


FIG. 78


FIG. 79

Phoma sp. (Foot Rot)

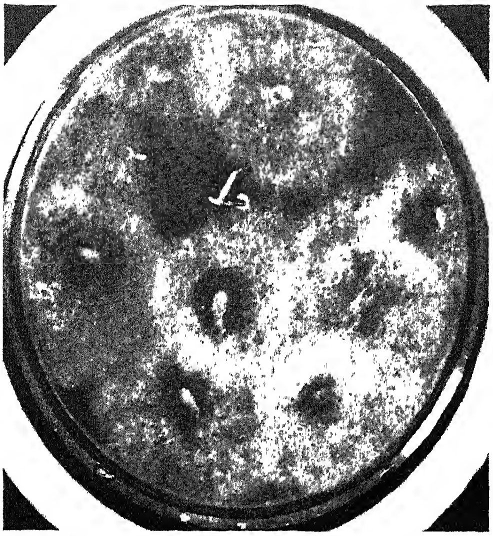


FIG. 80

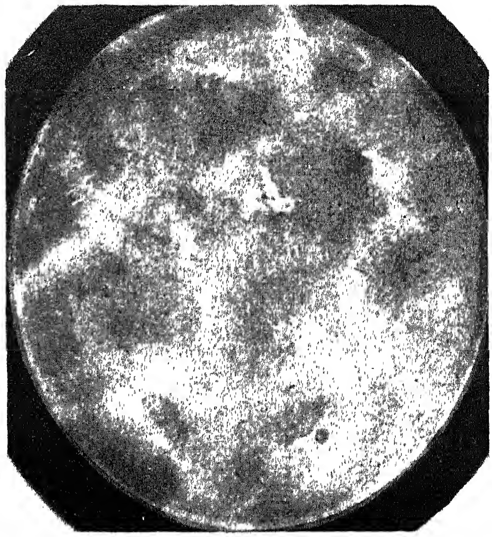


FIG. 81

Botrytis cinerea (Grey Mould).

FIG. 82

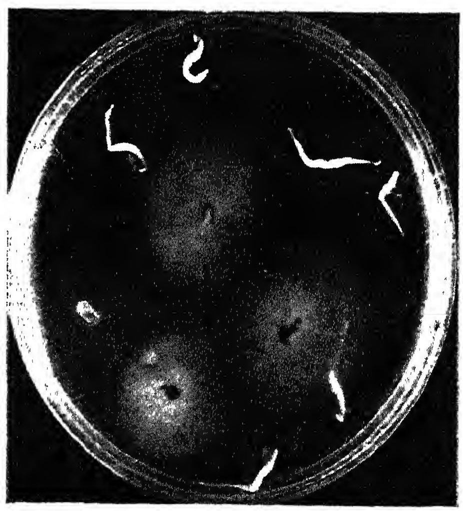


FIG. 83

Fusarium Lini (Wilt).

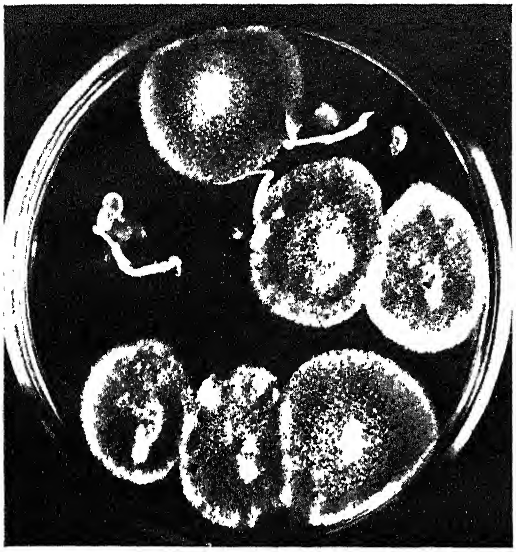


FIG. 84

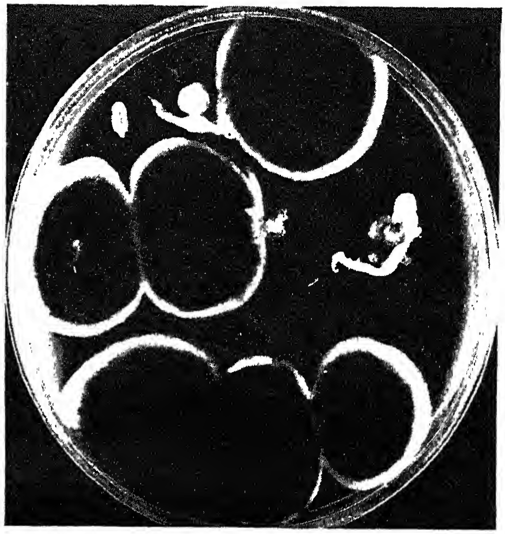


FIG. 85

Alternaria linicola

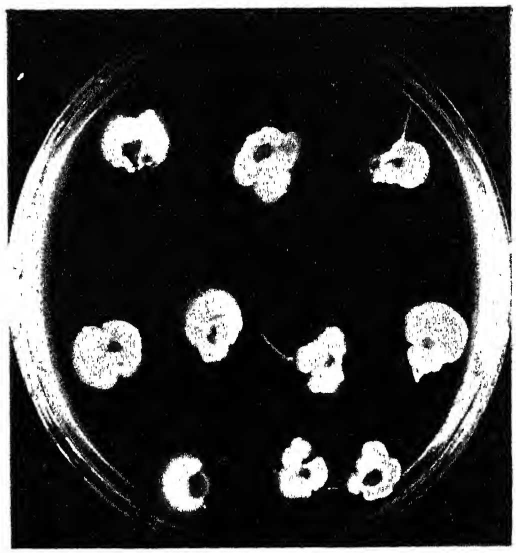


FIG. 86

FIG. 87

Penicillium sp.

APPENDIX II

Seed Disinfection

The treatment of seeds to destroy harmful parasites which they may be carrying but without injuring their germination capacity or their ability to produce normal plants is of long established practice. Exposure to the heat and light of the sun, steeping in urine, and the use of solutions of common salt, copper sulphate, or formaldehyde have all been popular methods in their day while hot water steeps are used to rid seed of internally borne parasites which are deep seated. The outstanding feature of the past quarter century, however, has been the discovery and use of organo-mercury compounds, in the form of dusts or in solution, as seed disinfectants. The discovery that organo-mercury compounds can be so effective has been vigorously pursued by the chemical industry with the result that a wide range of proprietary products recommended for use as seed disinfectants have become available in recent years. It is largely for the treatment of cereal seeds for the prevention of such smut diseases as can be controlled by disinfection, and diseases caused by species of *Helminthosporium* and *Fusarium* that these materials are used and their application has become world wide.

Less attention had been given to the control of seed-borne diseases of flax by seed disinfection although early recommendations had been made in the United States and in Canada for the treatment of oil flax seed by sprinkling it with a weak solution of formaldehyde for the destruction of spores of the wilt organism—*Fusarium Lini* (q.v.). In Ireland the problem as it concerned fibre flax received serious attention from 1917-1922 when it was found that formaldehyde could be used satisfactorily as a disinfectant, but, unfortunately, the strength of solution required was such as to cause injury to the germinating seed and thereby preclude its use in general practice. This finding was confirmed in later work carried out from 1939-1941. Where experiments were made with organo-mercury preparations the results were usually inconclusive and too little indication was given of the diseases for the prevention of which they were used. In Ireland it is not the practice in normal times to produce the flax seed required for the fibre crop, the seed required coming from western Europe or Canada. Owing to the steady shrinkage in the acreage of the crop from 1922 onwards and the generally failing interest taken in flax there was little stimulus for flax disease research and no attempt was made to study the problem seriously since then. The position changed in 1938 when a few epidemic outbreaks of stem-break and browning occurred in Northern Ireland. Although nothing could be done at the time to prevent the damage which was being caused, this epidemic provided an opportunity for confirming that the responsible organism—*Polyspora Lini*—is carried by the seed and it was in the course of this work that the Ulster method was devised to examine seed samples for the presence of parasites.*

* It was observed at the time that the seed from which all the affected crops were produced came from Denmark. Outbreaks of such a serious nature have never been

The outlook for the flax crop altered with the outbreak of the 1939-45 war. It soon became evident that the United Kingdom would not only have to become almost self-sufficient in the production of flax fibre but also in the production of sowing seed. A similar but less serious crisis had occurred in 1914-18 when it was found necessary to produce seed at home and when it was also found that seed saved in Ireland was apt to carry fungal parasites liable to cause grave damage to the crop. Although the life histories of *Colletotrichum linicola* and *Polyspora Lini*, the organisms responsible for seedling blight and stem-break and browning respectively were well known by 1922, no method for effective seed disinfection had yet been discovered. In 1939, the outlook was more propitious because heavily contaminated samples of seed required for experimental work could be readily selected by using the Ulster method and the introduction of organo-mercury compounds had brought a new aspect to bear upon the problem of seed disinfection.

The urgent necessity for the production of healthy flax seed during the period of the war, made it clear that a satisfactory method of seed disinfection would be an essential requisite towards this end and in the winter of 1939 the problem was attacked in earnest.

The two most serious seed-borne parasites likely to be encountered were *Colletotrichum linicola* and *Polyspora Lini* and bulk samples of seed heavily contaminated with these fungi were immediately selected for experimental work. Following upon methods which had already been devised in Northern Ireland for the evaluation of seed disinfectants for the control of *Helminthosporium* disease of oats, it was found that, with slight modification, the Ulster method for flax seed examination, could be used for the rapid evaluation of seed disinfectants in the laboratory. Such tests, which could be made at any time, and which only required some 7-10 days for their completion, cut out the necessity for taking the work immediately to the field and avoided the limitation of being able to carry out only one set of experiments in the growing season. By adopting this technique it was possible to examine the behaviour of hundreds of likely seed disinfectants in the laboratory during the winter season of 1939-40. Subsequent work carried out in the laboratory and in the field has now shown beyond doubt that the laboratory method has a high degree of reliability and that it is only necessary to take those disinfectants of the utmost promise to the field for confirmation of their behaviour in the laboratory.

---

encountered in the case of seed from any other source and this raises the question as to whether the climatic conditions prevailing in Denmark are particularly suitable for the development of this parasite and the onset of stem break and browning. Denmark is not far removed from the Netherlands and it might be argued that seed produced in the Netherlands should be subject to similar contamination although, in fact, seed from the latter country has not so far been found to be contaminated to nearly the same extent. Support is given to this observation by the results obtained from the flax seed health survey made in the United Kingdom where it has been found, even in this small area, that the comparatively small variations in climate may exercise a very marked effect upon the presence of fungal parasites carried by the seed.

None of the simpler chemical compounds likely to be readily available at a low cost proved to be effective and organo-mercury compounds did not give results of the same order as in the case of cereal seeds. To be moderately effective organo-mercury dusting powders such as " Agrosan " and " Ceresan " had to be used for flax at a rate of more than 20 oz. per cwt. (11 gm. per kg.) of seed. This is explained by the smooth slippery nature of the flax seed coat which does not allow the dust to adhere as in the case of cereal seeds. Had such treatment been recommended on a large scale not only would it have proved extravagant but it might have been dangerous because these compounds are poisonous and as flax seed is nearly always sown broadcast (using a " fiddle " sower) in Northern Ireland, the excess powder used in dressing the seed would have exposed the sower to the risk of mercury poisoning. That organo-mercury dusting powders can be effective for the control of seed-borne diseases of flax when used at a lower dosage rate was proved by employing the fixation method of seed treatment. Here the seed is first of all mixed with the requisite quantity of dusting powder and then with a sufficient quantity of water or skimmed milk to make the dust adhere to the seed. The quantity of liquid used (0.9 gall. per cwt. or 80 ml. per kg.) is so small as to allow the seed to dry off naturally when bagged after treatment and is insufficient to cause it to lump together in such a way that it will not separate easily when dry and ready for sowing. This method has been found to be quite effective using an organo-mercury dust at the rate of 12 oz. per cwt. (6.7 gm. per kg.) of seed, which quantity is in close agreement with the 5-6 oz. per cwt. required for seed oats when it is taken into account that the surface area of flax seed is approximately 2.5 times as great as that of a similar weight of seed oats. In spite of its efficiency, the fixation method was ruled out for general practice owing to the necessity for double treatment of the seed.

Results of about the same order as those given by the fixation method were obtained by using an organo-mercury compound (" Ceresan U.564 ") in solution and applied to the seed by the short wet method of treatment. This method depends for its efficacy upon the use of a disinfectant in liquid form, the spreading power of which is such as to allow the use of a very small volume to ensure the covering of the seeds. The quantity of liquid required is so small as to allow the seed to dry naturally after bagging, no special drying process being necessary. For flax seed it was found that treatment with an 8 per cent. solution of " Ceresan U.564 " applied at the rate of from 0.7-0.9 gall. per cwt. of seed (60-80 ml. per kg.) was effective. The seed dried quickly after treatment and little if any trouble was caused by the seeds adhering together especially if the precaution was taken to dry the seed to a moisture content of 5 per cent. instead of the 10 per cent. required in normal practice (see Appendix III). For carrying out the short wet method of treatment on a large scale suitable machinery is necessary if the work is to be done effectively and the non-availability of such machinery was one reason for not adopting the method on a wide scale in general practice. The

method was first evolved in Germany for use with cereal seeds and suitable types of hand and power operated machines had been designed in that country for carrying out the work. Prior to 1939 the short wet method was steadily gaining ground in Germany where it was superseding the dusting method in popularity. One suitable machine (see Appendix III) was available in Northern Ireland and large scale trials were successfully made with good results using the short wet method. This method has much to commend it in that the use of a poisonous dusting powder is avoided and operators prefer it both in so far as seed treatment and sowing are concerned. At the same time seed treated in this way must be sown within three months after treatment as the germination becomes impaired by prolonged storage, whereas seed treated by dusting will keep almost indefinitely. More may be heard of this method in the future but the fact that the requisite equipment is expensive and the use of a liquid is involved will not encourage a change over from dusting unless the advantages are well worthwhile and the method has been shown generally to be preferable by the time new equipment is necessary.

During the course of the investigation the chemical industry was approached and requested to supply samples of materials for testing purposes which were thought likely to make possible disinfectants. Working samples of a large number of compounds were received and an unexpected and surprising result was obtained from one of them which contained tetramethylthiuram disulphide as its active constituent. This material was submitted by Messrs. Imperial Chemical Industries, Ltd., and was in the form of a fine white powder. When used at the rate of 12 oz. per cwt. of seed (6.7 gm. per kg.) it was found to be completely effective in controlling *Colletotrichum linicola* and to provide a large measure of control in the case of *Polyspora Lini.* The material showed greater adhesive powers for flax seed than organo-mercury dusts and it was stated to be relatively non-poisonous. In support of this, pigeons and calves fed for a long period with flax seed very heavily dressed with this substance suffered no ill effects. This finding was encouraging for here was a material which, if it could be made available in sufficient quantity, would be largely effective in controlling the two seed-borne diseases which had proved so harmful to the flax crop in 1914-18 ; it was relatively non-poisonous, effective at a reasonable dosage and machinery for large scale seed treatment could be made readily available. An increase in the presence of *C. linicola* as a seed-borne parasite had already been observed in home produced seed and the position was such that immediate action was desirable. It was therefore decided to make arrangements for the disinfection of all flax seed produced in Northern Ireland in 1940 for sowing in 1941.

Through the good offices of the Ministry of Supply and Messrs. Imperial Chemical Industries, arrangements were made for the manufacture and supply of an adequate quantity of the new disinfectant, now styled " Nomersan," and Strickland machines (see Appendix III) for the disinfection of the seed were installed at the seed production centres.

The operation was thus introduced as routine practice and it proved to be both satisfactory and successful. Great Britain followed suit in 1941 and from that time the disinfection of all fibre flax seed produced in the United Kingdom has been generally practised.

It was shown as the result of field trials and general experience that disinfection of the seed had prevented serious outbreaks of seedling blight and stem-break and browning and no difficulties whatsoever were encountered until 1944 when foot rot caused by *Phoma* sp. (q.v.) occurred in epidemic form in the northerly and westerly districts of the United Kingdom. It was proved that the responsible organism was being seed-borne and that seed produced to the north and west was liable to heavy contamination. Unfortunately " Nomersan " proved to be only partially effective in controlling the disease and the short wet method, using " Ceresan U.564," although more effective, could not be practised on a large scale. A search was again made for a better disinfectant and through the good offices of the Ministry of Supply a range of products used in the United States were obtained for experimental purposes. Two of these materials proved to be superior to " Nomersan " for foot rot control ; they were " Granosan " (" New Improved Ceresan ") containing ethyl mercury phosphate as the active constituent and "Arasan" containing tetramethylthiuram disulphide. " Granosan," although the more promising, was ruled out on account of its very poisonous nature and " Arasan " was selected for use providing bulk supplies could be made available. This was again arranged for by the Ministry of Supply and in 1945 " Arasan " was substituted for " Nomersan " in Northern Ireland. As it was not completely effective, a comprehensive health survey of all seed samples was made using the Ulster Method and the seed was divided into two categories according to the extent of its contamination with *Phoma*. Bulks contaminated to an extent of 5 per cent. or less were disinfected and earmarked for sowing while those showing heavier contamination were not disinfected and were earmarked for crushing.

During the course of the examination of seed bulks for contamination with *Phoma* it was found that reliable information could only be obtained from samples in which the seed had been thoroughly mixed. This is believed to be accounted for by the occurrence of foot rot in patches in the crop so that the seed from the crop would tend to be unevenly contaminated after processing. The difficulty was overcome by installing mechanical mixing machines (see Appendix III), of the type employed for mixing animal feeding stuffs, at the processing centres and by their use ensuring the thorough mixing of the seed before its examination. After their installation, tests were made to determine how they would serve for carrying out the process of seed disinfection as well as seed mixing. These tests showed that they were eminently suitable for the purpose and so effective were they in ensuring an even distribution of the powder over the seed that from then on the use of the Strickland machine was discontinued and disinfection was carried out in the mechanical mixers.

There can be no doubt that the disinfection of flax seed for the control of seed-borne parasites proved a great boon to the United Kingdom in a time of emergency. The all-in costs of seed disinfection do not amount to more than 2s. 6d. for sufficient seed to sow one statute acre and it has been calculated that during the war years it increased the value of the United Kingdom crop by some £2,000,000. *It has also proved to be an experiment of no little interest as it has shown how the total seed supplies necessary for a particular crop in any country may be taken over and disinfected under expert supervision with a generally beneficial result to that country.* This is, so far as is known, the first time that a task such as this has been undertaken. But, in normal times, the problem still remains, as to whether the policy of disinfecting contaminated seed is wiser than arranging for the use of seed free from contamination. During the war there was no alternative but with the Ulster Method available for the large scale testing of seed for contamination, it is now possible to examine seed for its state of health with the result that seed supplies may be systematically surveyed for their freedom or otherwise from parasitic contamination. Such a survey has already been made for flax seed produced in the United Kingdom with very interesting results and there is no doubt that by the aid of such examination, coupled with the judicious use of seed disinfectants which will be rendered even more effective by further research, the problem of the control of disease caused by seed-borne parasites will be greatly simplified and will cease to present some of the difficulties experienced in the past.

Only recently a comparatively new seed disinfectant, embodying some departure in type from those already available, has come to notice. This is "Panogen," a liquid dressing manufactured and widely used in Sweden. The active constituent is an organo-mercury compound which is present to the extent of 0.8 per cent. It is dispersed in an oil containing liquid carrier which makes up the bulk of the disinfectant. The principle of its use follows closely upon that of the short wet method and it has been found under test in Northern Ireland that the material is effective for controlling leaf spot and seedling blight of oats (*Helminthosporium Avenae*) when used at the rate of 0.36 pint per cwt. (4 ml. per kg.) of seed. Thus, only one tenth of the bulk of liquid is required than is the case with "Ceresan U.564" which is the standard disinfectant used with the short wet method. Its use with flax seed is under investigation. Although "Panogen" must be classed with the poisonous group of disinfectants, its appearance may register another progressive step in the improvement of the technique of seed disinfection.

REFERENCES

Colhoun, J. (1945). The prevention of seed-borne diseases of flax. III.—The dusting, short wet and fixation methods of seed disinfection in relation to storage of the seed. Ann. appl. Biol. 32, 34-37.

Lafferty, H. A. (1921). The browning and stem-break disease of cultivated flax (*Linum usitatissimum*) caused by *Polspora Lini* n. gen. et sp. Sci. Proc. R. Dubl. Soc. 16, 248-274.

Muskett, A. E. (1938). Biological technique for the evaluation of fungicides. I.—The evaluation of seed disinfectants for the control of *Helminthosporium* disease of oats. Ann. Bot. Lond., N.S.2, 699-715.

Muskett, A. E. (1944). The short wet method of seed disinfection. Ann. appl. Biol. 31, 218-221.

Muskett, A. E. and Colhoun, J. (1942). Biological technique for the evaluation of fungicides. II.—The evaluation of seed disinfectants for the control of seed-borne diseases of flax. Ann. Bot., Lond., N.S.6, 219-227.

Muskett, A. E. and Colhoun, J. (1943). The prevention of seed-borne diseases of flax by seed disinfection. Ann. appl. Biol. 30, 7-18.

Muskett, A. E. and Colhoun, J. (1944). The prevention of seed-borne diseases of flax by seed disinfection. II.—Comparison of the dusting, short wet and fixation methods of treatment. Ann. appl. Biol. 31, 295-300.

Muskett, A. E. and Colhoun, J. (1945). Control of foot rot (*Phoma* sp.) of flax. Nature, Lond., 156, 538.

Pethybridge, G. H. & Lafferty, H. A. (1918). A disease of flax seedlings caused by a species of *Colletotrichum* and transmitted by infected seed. Sci. Proc. R. Dubl. Soc. N.S.15, 359-384.

APPENDIX III

The Production, Certification and Disinfection of Flax Seed

In Northern Ireland, where some 100,000 acres of fibre flax were grown annually during the peak period of the war, the large bulk of the crop is dam retted and the seed was thereby lost for further use as the complete plant is immersed in the dam immediately after pulling. Only that portion of the crop which was to be green scutched or tank retted was available for seed production. The seed supply so obtained (1,200 to 1,500 tons per annum) would have been quite inadequate for the large Northern Ireland acreage but this deficiency was made good by seed supplied from Great Britain where the whole crop was either green scutched or tank retted and where seed in excess of local requirements was thus produced.

When, in 1940, it was decided to disinfect all sowing seed produced in Northern Ireland, it was also deemed desirable to test it carefully for quality in order to ensure the farmer against being supplied with low grade seed and to avoid the necessity of disinfecting seed the quality of which might be below standard. This involved the introduction of a comprehensive scheme for seed certification whereby the moisture content, purity and germination capacity of the seed were carefully checked. In handling this problem the seed was dealt with on a crop basis and at least one properly drawn sample was examined from every flax crop destined for seed production. Where the bulk exceeded 1 ton, two or more samples were drawn for testing. Each sample consisted of approximately 6 oz. (170 gm.) ; it was drawn by a qualified officer and forwarded to the laboratory in a tightly stoppered glass bottle to avoid any change in moisture content, subsequent to sampling.

Seed drying and estimation of moisture content.

Flax seed with a moisture content in excess of 10 per cent. loses its power of germination when stored for any considerable length of time. For this reason, and especially in the case of seed produced under the humid conditions prevailing in Northern Ireland, it is necessary to ensure the proper drying of the seed immediately after de-seeding the crop. To achieve this, each centre of production was equipped with seed drying equipment. The seed drier operates on the principle of allowing the seed to come into contact with warm dry air while passing slowly down through a wooden duct. The duct, which is made of plywood and is from 12-15ft. in height, is usually so arranged that the hopper at the top into which the seed is fed is easily accessible from the upper floor where the winnowing is carried out. The drying of the seed is carried out after it has been rough cleaned by winnowing and before the final cleaning operation by the use of indented cylinders. The seed passes down the duct where it meets a constant current of warm dry air the temperature of which is not allowed to exceed 122°F. (50°C.) The air is delivered up and across the seed by a fan situated at the base of the duct so that as the seed slowly

finds its way down over the baffles in the duct it is subject to a steady stream of fresh warm air which is delivered at about 1,500c.ft. per minute. By means of an adjustable setting at the bottom of the drier, the speed at which the seed is allowed to pass down through the duct may be varied and the time of drying thereby adjusted so as to ensure its moisture content being below the prescribed limit. In Northern Ireland, freshly produced flax seed has a moisture content varying from 14-20 per cent. and by the process of drying this has to be reduced to 10 per cent. or below.

The estimation of the moisture content of the seed was first undertaken by the steam oven method which, although reliable, requires a considerable bulk of equipment and occupies a great deal of time as each sample has to be dried in a steam oven for a period of 48 hours. Later, it was found that a " Carter-Simon " oven (Fig. 88) could be used for the purpose to

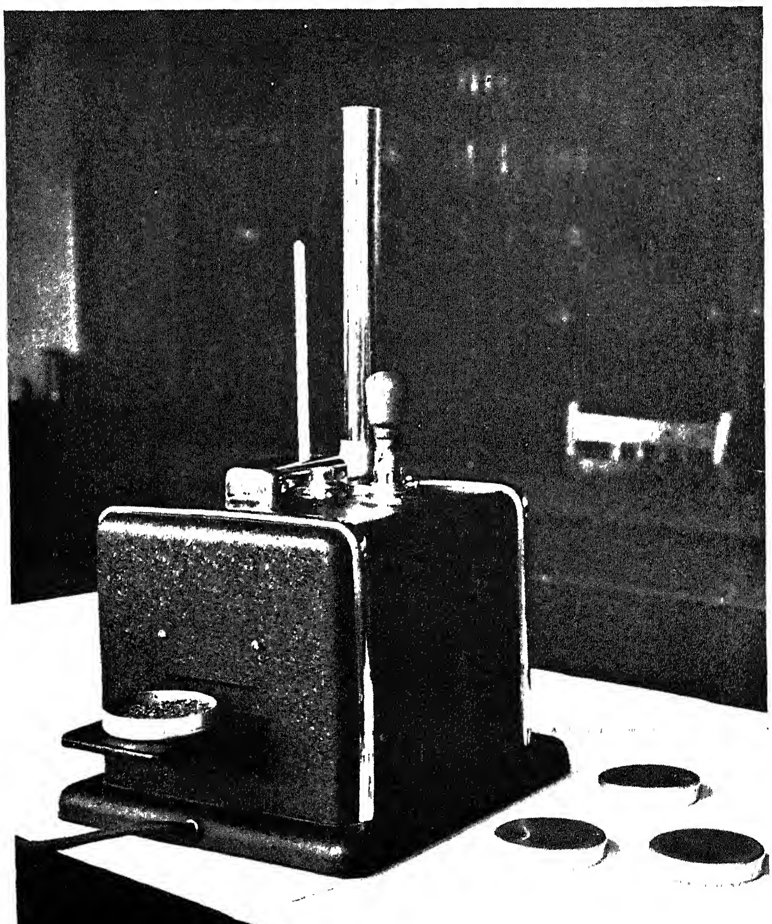


FIG. 88—The " Carter-Simon " oven as used for the estimation of the moisture content of flax seed.

give results which compared favourably with those obtained by the steam oven method. In using this equipment a sample of 5 gm. of seed is heated for 18 minutes at a temperature of 155°C. The saving of time realised in employing this method proved to be of considerable importance and greatly facilitated the progress of the work. Ultimately it was found that an electrically operated moisture meter could be successfully used and as this technique gave an instant result thereby again reducing the time required for the work, it was generally adopted. "Cambridge" moisture meters (Fig. 89) were found very suitable for the work and

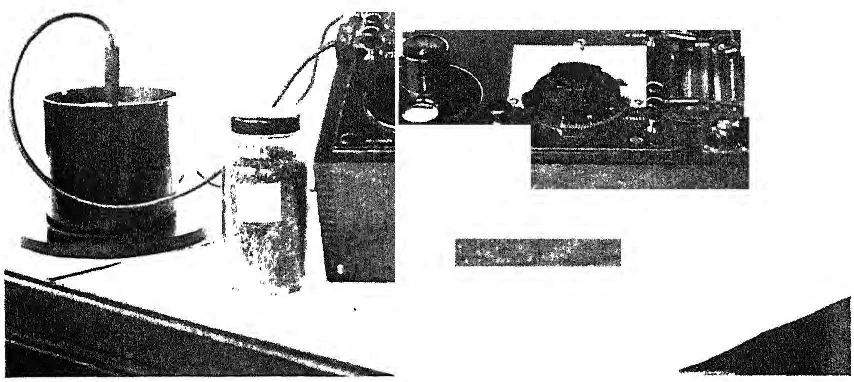


FIG. 89—An electrically operated moisture meter of the type used for the estimation of the moisture content of flax seed.

meters of this or similar type were installed at all centres of seed production in order to assist the management in drying the seed to the required moisture content.

Immediately the seed samples were received in the laboratory they were tested for their moisture content and if this was found to exceed 10 per cent., the production centre was requested to redry the bulk from which the sample was taken. If the moisture content was found to be 10 per cent. or less the sample was divided into two portions one of which was retained for examination for the presence of seed-borne parasites and the other forwarded to the Seed Testing Station.

Estimation of percentage purity and germination capacity

The Seed Testing Station reported upon the purity and the germination capacity of each sample and in order to help forward with the work,

obligingly issued an interim report stating the germination capacity of the seed after a 3-4 day period (a complete germination test requires 10 days after which time any seed which has not grown satisfactorily is counted as non-viable). Good quality flax seed germinates rapidly and as the great majority of seeds show satisfactory growth in from 3-4 days, the issue of an interim report assisted considerably towards the speedy completion of the work. All seed had to show a percentage purity of not less than 98 and if the figure for the sample was below this standard the management of the production centre was requested to reclean the bulk. Two qualities of sowing seed were allowed, i.e., first and second. First quality seed had to possess a germination capacity of 90 per cent. or over, while second quality seed was that of germination capacity between 80-89 per cent. Seed with a germination capacity below 80 per cent. was rejected for sowing purposes. In the first year or so when seed supplies were very scarce both first and second quality seed were used for sowing purposes but as time went on, the reduction in the quantity of second quality seed produced due to improved processing and the general increase in supply made it possible to discard second quality seed and use only that of first quality for sowing.

Examination for percentage contamination with seed-borne parasites

All seed samples were systematically examined by the Ulster method for the presence of seed-borne parasites but as the general precaution was being taken of disinfecting all seed as a matter of course, this work was spread out over the season until after 1944 when *Phoma* foot rot occurred in epidemic form. Owing to the widespread nature of the infection and as no disinfectant had been discovered which would eliminate completely the responsible fungal parasite from contaminated seed it was decided from then onwards to examine all seed samples for parasitic contamination before recommending their use for sowing purposes. It was also decided to discard all seed showing contamination with *Phoma* to an extent greater than 5 per cent. and to allow only seed with 5 per cent. contamination or less to be disinfected and sown. As this work involved the examination of many comparatively small seed bulks on a quantitative basis it was clear that the results obtained would not be reliable unless each bulk of seed was thoroughly mixed before carrying out the examination. The careful sampling of seed bulks had shown that there was a tendency for seed contaminated with *Phoma* to occur in pockets in the bulk ; a considerable variation in percentage contamination occurred even in different samples drawn from the same bag. This difficulty was overcome by installing at each centre of production a conical batch mixer of the type employed for mixing animal feeding stuffs. The capacities of the mixers used (Fig. 90) varied from 10 cwt. to 1 ton of seed according to the type installed and each lot of seed was mixed for 15-20 minutes. The operation was found to be effective and was adopted as routine from 1944 onwards.

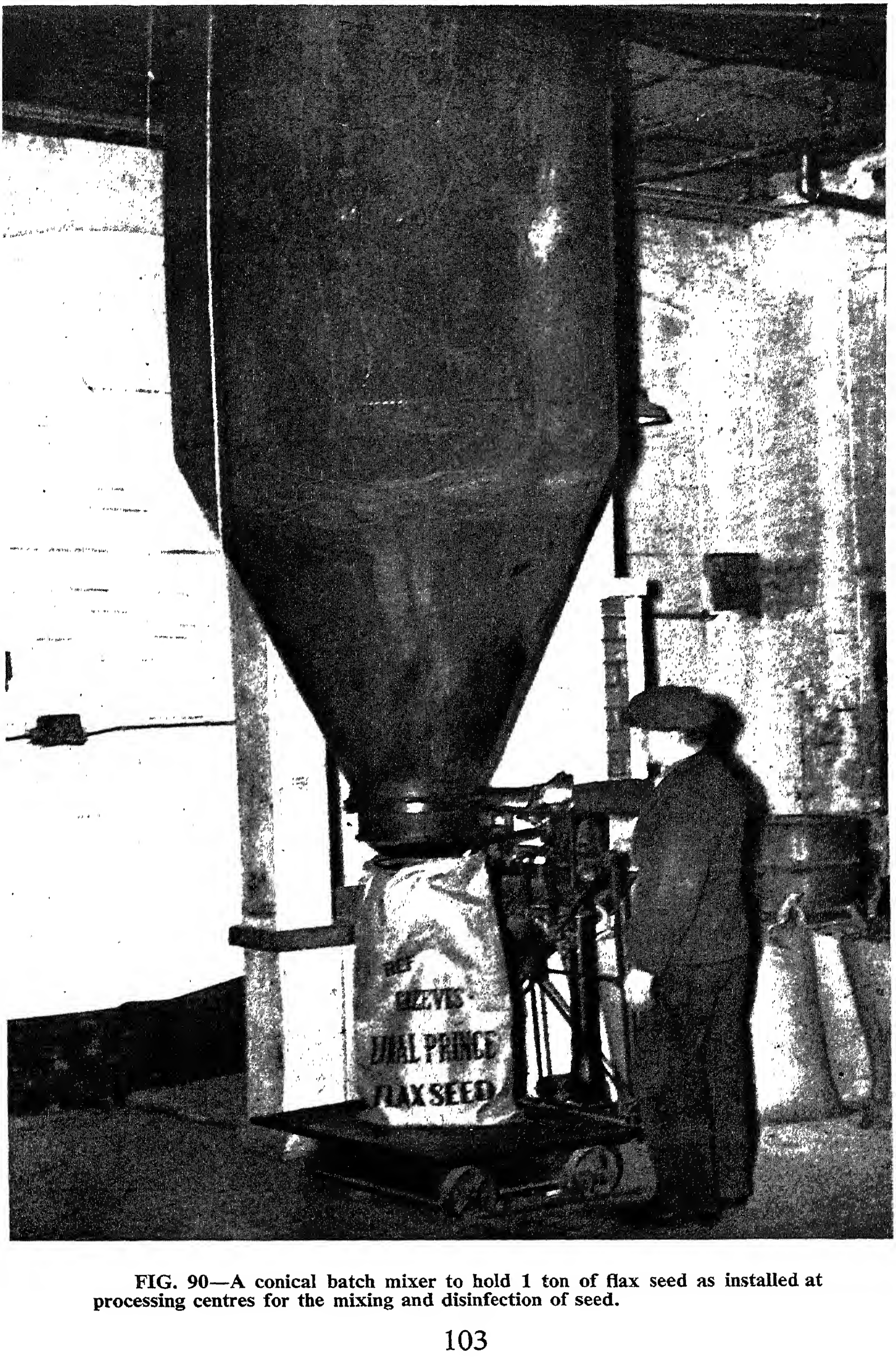


FIG. 90—A conical batch mixer to hold 1 ton of flax seed as installed at processing centres for the mixing and disinfection of seed.

Seed disinfection

When the quality of a seed sample had been shown to be satisfactory, authority was given for the disinfection of the bulk. " Strickland " machines (Fig. 91) were installed at the processing centres for this purpose. " Nomersan," at the rate of 12 oz. per cwt. of seed (6.7 gm. per kg.), was used until 1945 when it was superseded by " Arasan " which, applied at the same rate, proved to be more effective for the control of the foot rot parasite (*Phoma* sp.). The " Strickland " machine proved to be quite satisfactory providing the work was carried out under continual supervision. Such supervision was necessary because of the somewhat sticky

FIG. 91—A battery of two " Strickland " machines for seed disinfection installed at a seed processing centre.

nature of the " Nomersan " which did not always run freely through the distributor and was thereby apt to be unevenly applied to the seed. When, in 1944, conical batch mixers were installed for mixing the seed it was found, on test, that they could also act as almost perfect machines for seed disinfection and from that time onwards the " Strickland " machines were not employed for this work, the conical batch mixers being used in their place. The necessary quantity of the disinfecting powder was added to the seed in the mixer and after mixing for some 10-15 min. the powder was found to have been perfectly distributed throughout the whole seed bulk.

Bagging, weighing, sewing, labelling and sealing

The seed was bagged on emerging from the machine after disinfection. Each bag was weighed to contain 1 cwt. (approximately 51 kg.) and then carefully sewn with twine. Before sewing, a small leaflet was inserted in the mouth of each bag indicating to the farmer that the seed has been disinfected for the prevention of diseases liable to be caused by seed-borne parasites. A non-tearable label was then attached and by means of a code number stamped on the label it was possible to trace the seed to the original bulk from which it came. Finally, each bag was sealed in readiness for distribution to the merchant, who, in turn, supplied the seed to the farmer.

REFERENCE

Davin, A. G. (1928). A botanical study of the flax plant. VIII.—The storage of flax seed Res. Inst. Mem. Linen Ind. No. 50.

APPENDIX IV

A Healthy Flax Crop

Although much may be done by therapeutic methods to prevent and control crop diseases the attention given to such practice must not be allowed to overshadow that which is due to crop husbandry and hygiene. Seed disinfection, spraying, etc., must be regarded as useful and often necessary aids to health rather than as the only means of ensuring and maintaining health. Much more can be done by pursuing good husbandry and observing the principles of crop hygiene than is generally appreciated and it is sound advice to attempt to avoid disease by such methods and, at the same time, to be prepared to take the necessary action against disease should an outbreak occur.

A flax crop should not be grown in too rich or heavily manured land if it can be avoided. A crop rotation of at least four and, if possible, seven years should be followed and a good flax crop is normally taken immediately after cereals. Light or peaty soils are not generally suitable for fibre flax ; a good mixed loam is best and a cold heavy sub-soil is a safeguard against an epidemic attack of wilt. The land is not manured for flax although a dressing of 1 cwt. (51 kg.) of muriate of potash per acre will prevent the occurrence of flax yellows which is liable to cause crop losses in Ireland if the amount of available potash in the soil is too low. A very light dressing of a half to one cwt. (25-51 kg.) of sulphate of ammonia per acre may be useful in the case of starved or very poor land but the application of a nitrogenous fertilizer is seldom necessary or desirable.

Varietal resistance to disease in fibre flax may not be so marked and spectacular as is the case with certain potato diseases but, nevertheless, it is an aspect of flax cultivation which may assume increased importance in the future. It is possible that the future prospects for flax breeding lie more in the direction of producing varieties resistant to disease than in attempting to increase the fibre yield. In selecting the variety of flax to grow, a number of factors should be given careful consideration. Apart from the main consideration of the type and quality of fibre desired to give the greatest economic return under normal conditions, questions relating to the circumstances of local cultivation must receive attention. These include the soil type in which the crop is to be grown, the richness or poverty of the land, the possible tendency to lodging and disease resistance. Land prone to produce severely wilted crops should be avoided but if a mild attack is anticipated a wilt resistant variety, if available, should be chosen. Few fibre varieties show marked resistance to seedling blight or *Phoma* foot rot but recent evidence suggests that some varieties are resistant to stem-break and browning. Work in America, Australia and Russia has indicated the value of breeding varieties of both oil and fibre flax resistant to rust, a problem worthy of more serious attention in western Europe. It is of great importance that the most suitable variety should be chosen and expert knowledge together with local experience will be helpful in this respect.

Having selected the variety to grow, a choice of seed must now be made. The purity of the seed sample should not be below 98 per cent. and it should be quite free from seeds of redshank (*Polygonum Persicaria* Linn.) and other *Polygonum* spp. as well as dodder (*Cuscuta Epilinum* Weihe). Its percentage germination should lie between 95 and 99 and if below 90, the sample should be rejected. The energy of germination is of some importance ; vigorous flax seed germinates quickly and the germination capacity after a 3-4 days' test should be at least 90 per cent. The use of seed with a high germination energy is reflected in the evenness of the crop. Flax seed may carry a variety of harmful parasites capable of causing disease and it is desirable to obtain some information as to the extent to which the seed is contaminated by them. An excellent measure of control of many of these diseases may be achieved by seed disinfection but, at the same time, it is better to use seed comparatively free from such contamination if available and to disinfect the seed as a general precautionary measure. Cracked seed is liable to be further injured in the region of the cracking by common moulds which are present on the seed and in the soil. As seed disinfection is helpful in controlling such damage, this is a further reason for not neglecting to have it done. The fact that the disinfection of sufficient seed to sow one statute acre only costs 2s. 6d. supports the argument.

Consideration of the rate of sowing is important. To produce healthy well grown plants of the most suitable type it is usually reckoned that they should be spaced at the rate of one to each square inch of land. This means that an acre of land will be populated by some 6,272,640 or more than six and a quarter million plants, to produce which at least an equivalent number of seeds will be required. The size of flax seed varies according to variety and sample and an estimate of size is most conveniently obtained by calculating the weight of 1,000 seeds (the M weight) expressed as grams. In the case of an average sample of seed, the M weight is approximately 4.5 gm. from which it can be calculated that the weight of pure seed required to sow one statute acre is approximately 62.25 lb. (28.25 kg.). Providing the sample contains nothing but pure flax seeds, each one capable of growth, that a perfect seed bed is prepared, that no seed is wasted, that the spacing is ideal and that a season is encountered which is ideal for growth, sowing at this rate should give the desired result but so great is the gap between theory and practice that long experience has shown the most suitable sowing rate in Ireland to be at least from 80-84 lb. (36-38 kg.) per acre. Even so, the quality of the seed may affect the sowing rate and the example given at the foot of page 108 shows how the data available from seed tests may be used to help in arriving at a more correct sowing rate.

On the mainland of western Europe it is the usual practice to sow upwards of 1 cwt. (51 kg.) of seed per acre. Sowing at such a heavy rate has not often met with success in Ireland where it is difficult to understand why such a practice should be adopted on the continent although the reason will probably be found to lie in the differences of climate and the cultural practices followed.

Long experience has shown that the preparation of the seed bed is of great importance in the cultivation of flax. A fine firm seed bed is very desirable and careful growers, realising this, are prepared to take much trouble in its preparation. Flax seed is small and if rapid and even germination is to be obtained it is necessary for the seed to be in the closest contact with the soil particles with which it is surrounded. Flax requires moister conditions for germination than oats for whereas seed oats will germinate and grow in a soil with a moisture content of about 25 per cent., a moisture content of at least 30 per cent. is required to ensure the rapid germination and satisfactory growth of flax. Close contact made between seed and soil means the healthier and more vigorous growth of the seed and a fine seed bed helps towards this end.

The time for sowing flax seed is a matter which has given rise to considerable discussion but, on the whole, it may be said that in Ireland the tendency is to sow too late rather than too early. The reason for this may be found to be connected with the difficulties which are inherent in the management of a mixed farm. The flax plant grows rapidly and only requires approximately 100 days from the time of sowing to reach maturity : with the possible exception of turnips it is the last spring crop to be sown. These factors tend to encourage late sowing for if the season is late the sowing of corn and planting of potatoes will receive first consideration, while the short growing period required for flax makes the question of earlier sowing appear of less urgency than in the case of crops which take longer to reach maturity. It is not suggested that flax should be sown very early and the time for sowing will necessarily vary according to the earliness or lateness of the district, but it is undoubtedly preferable

Example :

A sample of flax seed has an M weight of 4.8 gm., a percentage purity of 98 and a percentage germination of 96. At what rate must this seed be sown to give a result equivalent to sowing seed with an M weight of 4.5 gm., a percentage purity of 100 and a percentage germination of 100 at the rate of 84 lb. (38.2 kg.) per acre ?

The percentage of pure seed capable of growth in the sample

$$= \frac{98 \times 96}{100} = 94.1$$

Therefore, the corrected sowing rate for percentage purity and germination

$$= \frac{84 \times 100}{94.1} = 89.25 \text{ lb.}$$

The M weight of the seed is 4.8 gm. and a correction for this must now be made as follows :

$$\frac{89.25 \times 4.8}{4.5} = 95.25 \text{ lb. } (43.3 \text{ kg.})$$

Therefore, in order to obtain the desired sowing rate with this sample of seed, it must be used at the rate of 95.25 lb. (43.3 kg.) per acre.

to get sowing done, if at all possible, during mid-April than to delay it until the end of April or May. Some of the arguments which can be advanced in favour of earlier sowing are as follows :—

The latter half of April and early May, when much flax is usually sown, is frequently a period of drought in Ireland. Sowing under such conditions results in the delayed germination of a proportion of the seed and the consequent occurrence of " second growth " in the crop.

Prior to this period there is usually more available moisture in the soil. Flax seed requires moist, compact soil if it is to germinate evenly and without delay. Earlier sowing will assist in securing these conditions and reduction of " second growth " in the crop will result.

The preparation of a fine and well compressed seed bed is of greater importance when the soil is very dry than when it is evenly moist. Such a fine seed bed is not so essential under damper sowing conditions.

Injury to the young crop likely to be occasioned by seed-borne diseases and possibly aggravated by the slower growth of the crop in its initial stages due to a lower soil temperature, is largely prevented by seed disinfection. Seed disinfection also ensures more even germination of the seed.

Damage by frost is liable to be exaggerated. Flax yellows, for instance, which is frequently believed to be due to frost, may be prevented by ensuring the presence of an adequate supply of available potash in the soil.

By earlier sowing, the growth of the seedling crop is more advanced at the time when attack by flax flea beetle commences. It will have largely grown through the susceptible stage and damage by this pest will be much less severe.

Flax rust is most severe in late sown crops grown in land too rich in available nitrogen. Earlier sowing constitutes an important factor in preventing crop attack by this disease.

Crop damage by browning is much more severe in late sown crops. Earlier sowing and earlier pulling coupled with the lag in the spread of browning resultant upon seed disinfection, will assist materially towards the safe harvesting of the crop before it becomes seriously affected with the disease.

Earlier sowing means earlier ripening. This allows the farmer much more time in which to handle the crop and helps to ensure its being saved in good condition.

In the case of crops intended for de-seeding, earlier sowing allows for the better maturing and ripening of the seed before pulling.

Evenness of sowing is of special importance. Uneven sowing results in the production of a mixture of fine and coarse plants which makes retting and scutching more difficult and lowers the value of the crop. The aim should be to obtain an even sample of moderately fine straw and here the even sowing of the seed is of great importance. Seedling diseases in so far as they kill out individual plants in the crop tend to produce a result similar to that caused by uneven sowing and it is of interest to note

that even sowing tends to lessen the damage caused by such diseases. Their first appearance is nearly always to be observed when the young plants occur in clumps resulting from uneven sowing. The conditions provided by such a clump of plants appear to be ideal for the outbreak and spread of seedling diseases and it has been observed that they are liable to spread much less rapidly and to do less harm when even sowing is practised and the plants are regularly spaced over the land.

In Ireland almost the whole of the flax crop is sown broadcast, sometimes by hand but usually employing a hand operated machine or "fiddle." In the hands of an expert this method gives excellent results and provided the after sowing harrowing is done at right angles to that given before sowing, so as to avoid dragging the seed into rows, a very satisfactory spacing of the seeds can be obtained. The seed can be drilled with equally good results and this method has perhaps an advantage over broadcasting in that a more even depth of sowing is achieved. In a time of drought sowing to an even depth may be advantageous in that the seeds may have more equal access to the available moisture with the result that the growth will be more regular and the tendency towards " second growth " lessened. At the same time the proximity of the plants in rows consequent upon drilling leads to the more ready spread of disease along the drills.

Once the seed has been sown and the final harrowing and rolling given the only further action which can be taken to ensure the successful growth of the crop is to keep it as free as possible from weeds and to prevent attack by leather jacket grubs. Weeds may be troublesome and they should be first removed when the crop is young and the plants about 3 inches in height. If necessary, a second weeding may be carried out from 2-3 weeks later. Charlock, which is frequently prevalent, may be controlled by spraying the crop with a 2.5 per cent. solution of copper sulphate (10 lb. (4.5 kg.) copper sulphate to 40 gall. (1.82 hl.) water). To be effective and to cause no injury to the flax, spraying should not be delayed longer than the time of the first weeding and the spray should be applied at the rate of 60 gall. (2.75 hl.) per acre. The operation should not be carried out during a drought or at a time when weather conditions are unfavourable for the growth of the crop. Spraying will check the growth of some other weeds such as spurrey (*Spergula arvensis* Linn.) and chickweed (*Stellaria media* Vill.) but it will have no effect upon redshank and other species of *Polygonum*. When the crop has been checked or when weed competition has been so serious as to impoverish the growth, the addition of 2 stones (13 kg.) of nitrate of soda to each 40 gall. (1.82 hl.) of spray will help to stimulate the growth and invigorate the crop.

Although early ploughing and the preparation of a fine firm seed bed will help to prevent damage by leather jacket grubs, some harm to the seedling crop may be caused by these pests especially if it follows on lea land. Where such damage is anticipated it may be largely prevented by applying the following poisoned bait treatment. The bait is prepared by mixing 1 lb. Paris Green with 28 lb. bran and moistening the mixture with water or with water to which a small quantity of treacle has been

added. It is broadcast evenly over the young crop just at the time when an attack is anticipated or immediately the first signs of attack are observed. The quantity mentioned is sufficient to treat one statute acre and the application should be made in dry weather. If wet weather sets in soon after the bait has been applied it may be necessary to repeat the treatment. As Paris Green (copper aceto-arsenite) is very poisonous great care should be taken to ensure that the bait is not left where it is accessible to livestock or poultry.

The growth and development of the crop must now depend upon the season but whether this be favourable or unfavourable, the results obtained will depend to no small extent upon the way in which the preliminary preparations have been made. A severe hail shower in early summer may cause unavoidable damage and in some seasons an attack of rust may occur in spite of precautions which have been taken. Continued heavy rains with a humid atmosphere towards the end of the growing season may cause the crop to become lodged and severely attacked by grey mould but these occurrences are exceptions rather than the rule and if all due precautions have been taken, serious outbreaks of disease are not to be expected. Even in cases where unavoidable difficulties are encountered, the ingenious grower will often manage to keep losses at a minimum.

The story of a good flax crop is, however, not completed with the pulling of the crop or even with its retting. The value of the crop is dependent upon the fibre it produces and every care must be taken to ensure that it reaches the scutch mill in such a condition that the greatest quantity of good quality long fibre is obtained. The great danger is, of course, loss of fibre through the action of grey mould and other micro-organisms upon the damp straw. In a wet climate such as prevails in Northern Ireland this is often difficult to prevent and very serious damage frequently results from the straw becoming *rotted* and the fibre denatured to such an extent as to destroy its value, by the action of micro-organisms.

Crops to be dam retted are normally placed in the dam immediately on pulling for the specific purpose of exposing them to the action of micro-organisms which " *ret* " the straw and thereby make the fibre easily separable from the other tissues. But " *retting* " does not mean " *rotting* " and when once the *retting* process is completed the crop must be dried and kept dry in order to prevent the action from going too far and *rotting* the crop. The rapid and thorough drying of the retted crop when it leaves the dam is not always an easy matter in Northern Ireland but it should never be forgotten that it is at this stage so much damage is frequently caused which results in the loss of fibre. Whether or not it will eventually be possible to dry the crop under cover or by artificial means will depend upon the expense of the operation in relation to the benefit obtained. Careful growers are fully aware of the problem which the drying of the crop presents and it is often surprising how, by their experience and ingenuity, they are able to achieve good results in the face of great difficulty.

A similar problem arises in the case of crops intended for green scutching. Here, because of the impossibility of the immediate handling of the crop in the mill, it is usually necessary to build it into a stack for a considerable period before scutching. Unless the flax can be stacked dry and kept dry severe losses will be inevitable through the action of grey mould and other micro-organisms in the period intervening between pulling and scutching.

In Northern Ireland, therefore, it is of the utmost importance to make every effort to ensure the *dry condition* and *good handling* of flax from the time of pulling until scutching if every advantage is to be gained from the expense and labour involved in growing a good crop.